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DECAPOD CRUSTACEAN FAUNA OF SEVEN AND ONE-HALF FATHOM REEF, TEXAS: SPECIES COMPOSITION, ABUNDANCE, AND SPECIES DIVERSITY

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ABSTRACT

The decapod crustacean fauna of a sublittoral hard substrate off South Texas near 26° 49.0′N, 97° 19.3′W was investigated to determine species composition, abundance, diversity, spatial distributions, and seasonal variations. SCUBA was used to conduct *in situ* counts and collect epifaunal materials, sediment, and rocks from which decapods were removed. Stomach contents of predatory fish were examined.

The decapod fauna on Seven and One-half Fathom Reef showed a significant tropical component. The alpheid shrimps *Synalpheus fritzmuelleri* and *Synalpheus apioceros*, the diogenid hermit crab *Paguristes hewatti*, and xanthid crabs of the genus *Pilumnus* were most abundant in samples from the heavily fouled reef surface; in sediment and diogenid *Paguristes hummi* predominated; on loose boulders the xanthid crab *Pseudomedaeus agassizi* predominated and large individuals of the porcellanid crab *Petrolisthes galathinus* were commonplace. Of the 66 decapod species collected during studies on Seven and One-half Fathom Reef, about one third had not been previously reported from the Texas Coast.

The variety of reef habitats available and the geographical location of the reef probably account for the species composition, abundance, and diversity of decapods present. A seasonal variation in species diversity was noted for decapods associated with the reef surface; seasonality in occurrence and reproductive activity were documented for a number of species. Benthic reef fishes were found to prey extensively upon reef crustacean fauna, but nektonic fishes preyed upon crustacean species typical of the outlying level bottom.

INTRODUCTION

The present work results from one of several ecological studies conducted on a sublittoral rock outcrop in the northwestern Gulf of Mexico. Tunnell and Chaney (1970) and Tunnell (1973) previously reported on molluscan fauna of the reef. Other studies have concerned reef fishes (Causey 1969), echinoderms (Shirley 1974), and polychaetes (McCarty 1974). Investigations of additional invertebrate groups on the reef are in progress.

Current knowledge of northwestern Gulf decapod crustacean fauna has accrued from numerous systematic and ecological papers, most of which are reviewed in recent summaries of Gulf of Mexico and Caribbean decapod groups. Chace (1972) reviewed pertinent literature, provided keys, and discussed distributions for almost all western Atlantic shallow-water shrimps including most from the northwestern Gulf. Deep-water natantians were summarized in studies by Roberts and Pequegnat (1970) and Pequegnat, L. (1970). Reptantians from the shallow northwestern Gulf were reviewed by Felder (1973b) and deep-water forms were treated in studies of Gulf deep-water anomurans (Pequegnat and Pequegnat 1970) and brachyurans (Pequegnat, W. 1970). Powers (1977) recently has cataloged existing records of Gulf Brachyura.

Surveys of northwestern Gulf decapod fauna in the past were conducted primarily with trawls, seines, and dredges in level-bottom areas relatively free of obstructions. Decapods associated with hard substrates received little attention except in a preliminary survey of coastal jetties (Whitten, Rosene, and Hedgpeth 1950) and an unpublished survey of benethic invertebrates near Heald and Sabine Banks off the upper Texas coast (Hulings 1955). More recently, decapods from the West Flower Garden Bank at the outer edge of the Texas-Louisiana continental shelf were reported (Pequegnat and Ray 1974). SCUBA techniques provided efficient means for sampling benthic crustaceans in the Heald-Sabine and Flower Garden Bank studies as well as in the present investigation.

The present study was undertaken to describe a previously uninvestigated assemblage of benthic decapods associated with a small sublittoral area of hard substrate. This report provides a checklist of reef decapods with quantitative assessments of species abundance, diversity, spatial distributions, and seasonal variation. Few such quantitative data are presently available for decapod crustaceans or other invertebrate assemblages in the northwestern Gulf of Mexico.

STUDY AREA, MATERIALS, AND METHODS

Description of Reef

Seven and One-half Fathom Reef is near 26°49.0′N, 97°19.3′W in an area of generally converging north and south bound currents (Fig. 1). It is in 14 m of water and measures approximately 350 m along its northwest to southeast length. The reef's rocky substrate is composed of a "well indurated calichified lake marl" of late Pleistocene origin (Thayer, LaRocque, and Tunnell 1974).

Fathometer tracings and diving observations indicated four rises along the length of the reef, the largest of which was chosen for location of a study transect spanning the width of the rocky structure and portions of the adjacent bottom (Fig. 2). Topography within the transect is typical of the larger rises; tabular slabs of rock separated by offsets and shallow crevices form the top, while slopes are more deeply creviced and vary from cliffs to staircases of boulders broken from the main structure.

Sediments in reef crevices and on the deeper inshore bottom are primarily a mixture of mud and sand. On the offshore bottom, a dense accumulation of mollusk shells and shell fragments extends to about 15 m beyond the edge of the rocky substrate. This area and a 15-m width of scoured sediments on the inshore bottom were included in the transect because their structure and composition differed from that of outlying bottom areas.

Boring mollusks, sipunculans, and other organisms have extensively eroded the top and upper slopes of the reef which are heavily encrusted by a mat of epifaunal fouling organisms (Fig. 2).

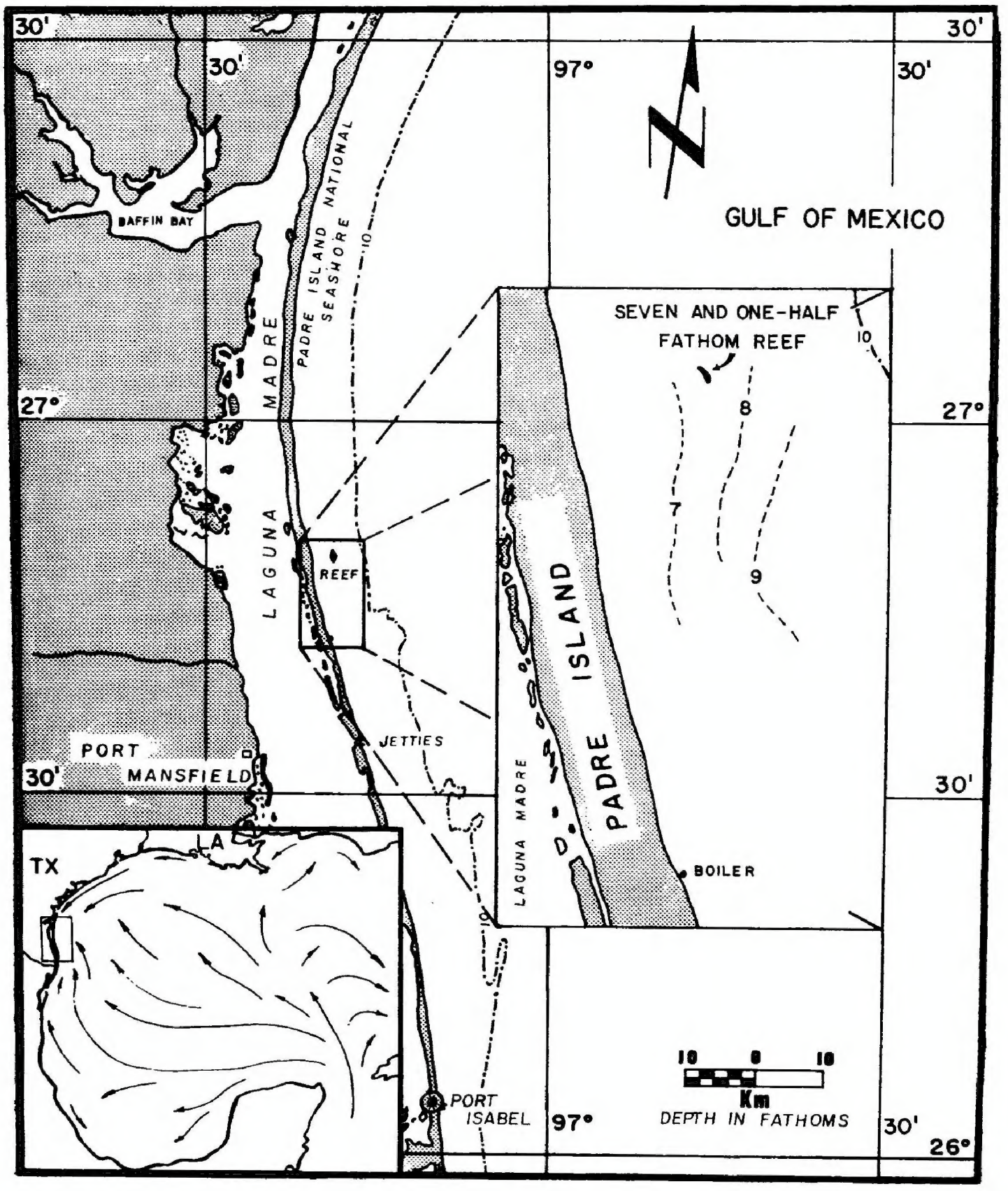

FIG. 1. Map of lower Texas coast showing location of Seven and One-half Fathom Reef (modified after Tunnell and Chaney 1970). Lower insert of current patterns is generalized from those of Hedgpeth (1953) and Leipper (1954).

Tunnell (1973) reports the pelecypods *Lithophaga bisculata* (d'Orbigny), *Gregariella coralliophaga* (Gmelin), and *Rupellaria typica* (Jonas) as the most abundant boring mollusks on the reef and notes the sipunculan *Phascolosoma antillarum* Grube and Oersted to be common in most rocks.

The mat of fouling organisms, hereafter referred to as "fouling mat," is predominantly tubes of the polychaete genus *Phyllochaetopterus* overlain by hydroids and compound ascidians (Plate 1). Sponges are scattered within the mat of tubes, on top of it, and on exposed areas of rock

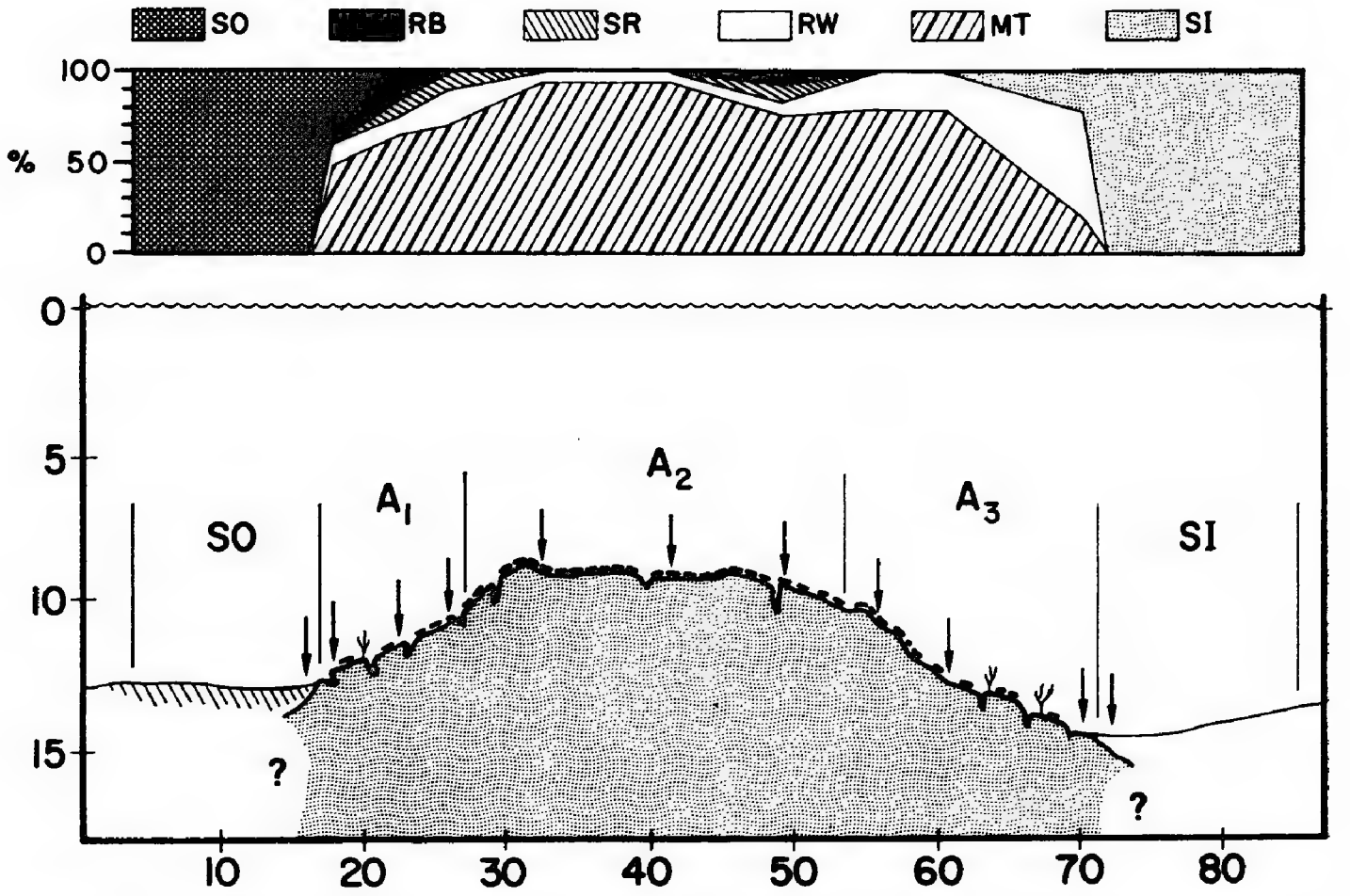

FIG. 2. Cross-section of study transect indicating sampling areas on sediment (SI and SO) and rocky substrate (A_1, A_2, and A_3). Cross-hatching on offshore bottom indicates dense shell fragment accumulation, heavy dashed line indicates dense epifaunal fouling mat, and branched symbol indicates areas with gorgonians. Depth and reef dimensions in meters. Upper figure gives percentages of substrates across transect as determined from quadrats dropped approximately where indicated by arrows on lower figure. SO = offshore sediment; RB = boulder-size rocks; SR = reef crevice sediment; RW = rock surface without fouling mat; MT = fouling mat; SI = inshore sediment.

surface. While usually 5–15 cm thick, the mat of *Phyllochaetopterus* is occasionally covered by hydroids to thicknesses exceeding 25 cm. In upper levels of the study transect, the fouling mat completely conceals the rocky surface and may exceed a volume of 45 liters/m². Density of *Phyllochaetopterus* tubes approaches 10,000/m² in this area (McCarty 1974). As depth increases on reef slopes fouling mat density decreases and gorgonians occur more frequently. The fouling mat was heavily sampled throughout the study and harbored dense concentrations of crustaceans, ophiuroids, polychaetes, and small mollusks.

Sampling and Processing of Samples

Decapods were most intensively sampled on monthly trips from April, 1970 to July, 1971, though some specimens were obtained as early as 1968 or late as 1973. Rough seas and turbid water did not permit routine collecting during trips in July, September, and November, 1970 nor February and April, 1971.

Field work was conducted from a small outboard boat. A Van Dorn water sampler containing a centigrade thermometer was used to obtain samples at the water surface, top of the reef and inshore bottom. Salinities were determined by refractometry. SCUBA was used to sample habitat materials and conduct *in situ* counts of decapods. Proportions of substrates within the transect were estimated early in the study by dropping a 1.0-m² quadrat marker once to each side of the points shown in Figure 2.

A systematic sampling survey, consisting of several passes through the 2-m wide study tran-

sect, was made on eight occasions between August, 1970 and July, 1971. On the first pass a 1.0-m^2 quadrat marker was dropped randomly—once to each side of the transect center line—in areas A_1, A_2, and A_3 (Fig. 2). Large decapods within the meter square were counted after each throw and recorded on an underwater slate. A 0.25-m^2 subsample of fouling habitat was taken from the first throw in each area and placed in a plastic bag for preservation in 10% formalin. The sample was later analyzed as follows: (i) fouling materials were washed over a 1.19-mm sieve and crustaceans were picked from residues; (ii) materials were then shredded by hand and immersed in salt solution to float out small crustaceans; (iii) shredded materials were drained and inspected under magnification for remaining crustaceans before final wash was made over a 1.19-mm sieve; (iv) decapods obtained by above methods were identified and counted (larvae were omitted from counts).

A second pass was made through the transect to count and observe large decapods not encountered in quadrat counts. For this count cracks, holes, and walls of crevices within the transect were carefully inspected.

Remaining diving time was utilized in collecting rocks (small boulders) and sediments near the transect or in collecting from other areas of the reef. Rocks were placed into canvas bags which were returned to the surface and submerged in 10% formalin. Decapods were later removed from bags and rocks, identified, and counted. Rocks were then drained, weighed, and measured.

Sediments were sampled at the inshore bottom, offshore bottom, and crevice bottoms by using in a hand scoop to excavate the upper 50 mm of sediment and placed into a plastic bag. Upon return to the surface 10% formalin was added. In the laboratory, samples were measured in liters, corrected to bottom surface area (1 liter = 0.02 m^2) and washed through a 1.19-mm sieve. Volume of mollusc shell fragments and counts of crustaceans were determined from sieve residues of each sample.

Additional data were obtained from study of museum specimens in Texas A&I University zoological collections and dissection of stomachs from predaceous fishes preserved during studies by Causey (1969). Studies on food habits of the red snapper, *Lutjanus compechanus* (Poey), were conducted by James K. Davis concurrently with the present study. Crustaceans from stomachs of *L. campechanus* and other predaceous fishes dissected during the study were identified for addition to the checklist and discussion of predator-prey relationships.

Interpretation of Quantitative Data

Estimates of abundance, diversity, and species richness were based upon 32 species taken in quantitative samples from the reef. Abundance of decapods from each substrate sampled was expressed as mean number of each species per 1.0 m^2. Decapods from monthly quadrat sample (subsample + *in situ* quadrat counts) were treated together as a sample of the reef surface which included both the extensive fouling mat and lesser areas of unfouled rocky surface (MT + RW of Fig. 2). For each of the eight months that quadrat surveys were made, counts from areas A_1, A_2, and A_3 were pooled, and a single monthly mean number per 1.0 m^2 was calculated for each species. The mean, range, and 95% confidence limits of these abundances were determined over the total eight months of quadrat surveys.

The sampling tool used on sediments (SO, SR, SI) removed approximately 0.02 m^2 of surface area for each liter of sediment taken, so abundance in sediment was expressed as number per liter and number per 1.0 m^2. Abundance in rock samples was scaled to number per 1.0 m^2 of surface occupied by rocks; 22 rocks were measured and found to occupy a total area of 0.733 m^2. For determination of a "Transect Overall" count, the pooled total counts for each substrate were weighted in proportion to the percent of area each occupied within the transect (Fig. 2).

Shannon's diversity index, H′ (Shannon 1948), and $E(S_n)$ of Hurlbert (1971) were chosen to express species diversity and species richness, respectively. H′ was calculated for $\log_{10}$ using the tables of Lloyd, Zar, and Karr (1968). The evenness component of diversity was calculated after Pielou (1969). Dominance index, DI, was calculated after McNaughton (1967) and is the combined relative abundance of the two most common species.

Plate 1. Epifaunal fouling mat from upper surface of Seven and One-half Fathom Reef. In upper sample the tangled *Phyllochaetopterus* tubes have been shredded by hand to remove crustaceans; lower sample is intact and shows cross-section of fouling mat with *Phyllochaetopterus* tubes overlain by various compound ascidians.

H′ was calculated for counts from each quadrat sample taken; effects of areas and months on changes in H′ were determined by analysis of variance. Mean values of H′ were determined across both months and areas. All quadrat counts were pooled to determine an overall value of

H′ for the reef surface ("Total Quadrat Samples") which was used in comparison to H′ values for overall counts from each of the other substrates (RB, SO, SR, SI).

The weighted "Transect Overall" count was used to calculate an overall transect diversity. This procedure was similar to that used by Lloyd *et al.* (1968) to infer species diversity for the entire community. To derive this count, the total quadrat counts were used without adjustment as the total area covered by eight months of quadrat samples was assumed proportional to the percent (60.2%) of the transect which was occupied by the reef surface (MT + RW in Fig. 2). This necessitated weighting of samples from boulders and sediments to higher counts (larger numbers) expected in their respective percentages of a hypothetical transect area $\frac{100.0\%}{60.2\%}$ or 1.66 times that covered by quadrats. As a result of this weighting procedure, the mean calculated "Transect Overall" diversity value is possibly somewhat lower than actually exists.

The estimated number of species $E(S_n)$ for a given number of specimens (n), termed a measure of "species richness" (Hurlbert 1971) or "rarefaction diversity" (Heck, Van Belle and Simberloff 1975) was calculated using the following equation from Hurlbert:

$$E(S_n) = \sum_{i=1}^{S} \left[1 - \frac{\binom{N - N_i}{n}}{\binom{N}{n}} \right]$$

where N is the number of individuals in the original sample, S is the number of species in the original sample and N_i is the number of individuals in the *i*th species. A rarefaction diversity curve of n vs. $E(S_n)$ was plotted for each month of quadrat sampling by pooling counts from the areas sampled. The quadrat counts for all eight months were pooled to plot the rarefaction curve for "Total Quadrat Samples." All counts from samples of each of the other substrates (RB, SO, SR, SI) were pooled to plot their respective curves. A "Transect Overall" rarefaction curve was plotted from the same overall weighted counts used for determination of the "Transect Overall" value of H′.

RESULTS

Composition of Decapod Fauna

A total of 66 species was identified among the more than 14,000 decapods collected from reef substrates and fish stomachs. Of these, 27 had not been previously reported from the Texas Coast. A list of species, with nominal references, months collected, months ovigerous, measurements, collection sources, and references to descriptions is given in Appendix I.

Among decapods taken from fish stomachs (Appendix II) 20 species were not found in collecting on the reef and the immediate adjacent bottom. There were *Penaeus aztecus azetecus*, *Trachypenaeus* sp., *Sicyonia brevirostris*, *Sicyonia dorsalis*, *Lucifer faxoni*, *Acetes americanus*, *Ogyrides limicola*, *Pagurus impressus*, *Pagurus pollicaris*, *Petrochirus diogenes*, *Albunea paretii*, *Hepatus epheliticus*, *Hepatus pudibundus*, *Parthenope serrata*, *Libinia* sp., *Arenaeus cribrarius*, *Callinectes sapidus*, *Callinectes similis*, *Portunus gibbesii*, and *Pinnixa lunzi*. Most of these were taken from nektonic fishes; stomachs of benthic fishes more frequently contained species common to reef habitats. The swimming crabs *Callinectes similis* and *Callinectes sapidus* were observed drifting in the overlying water column, but never on the reef itself.

Most range extensions and species with tropical affinities were found among the 46 species taken from the reef proper or the immediate adjacent bottom. Of

these, 14 were collected only in non-quantitative portions of the study and are not represented in further discussions of abundance and diversity. These were *Alpheus floridanus*, *Alpheus thomasi* (?), *Alpheus intrinsecus*, *Scyllarides nodifer*, *Polyonyx gibbesi*, *Dromia erythropus*, *Heterocrypta granulata*, *Ovalipes floridanus*, *Glyptoxanthus erosus*, *Platypodiella spectabilis*, *Macrocoeloma trispinosum nodipes*, *Mithrax acuticornis*, *Stenocionops furcata coelata*, and *Stenorhynchus seticornis*. Most of these were collections of single specimens before or after the period of time in which quantitative collections were made. *Stenorhynchus seticornis* occurred several times within the study transect though never in sufficient density to be collected in quadrat counts. The remaining 32 species were encountered in quantitative samples and were used to estimate abundance and diversity.

Abundance of Reef Decapods

Mean density of decapods within the entire study transect was 617/m² as determined from weighted "Transect Overall" counts including all substrates sampled. Quadrat sampling on fouled and partly fouled areas of reef surface (MT and RW) indicated densities of decapods which ranged from 642/m² to 1455/m² over eight sampling occasions. Mean density within the area covered by all quadrat sampling was 909/m². *Pilumnus* sp. [nr. *P. sayi*] was the most abundant species taken in quadrat samples, though *Synalpheus fritzmuelleri*, *Paguristes hewatti*, *Pilumnus pannosus*, and *Synalpheus apioceros* also occurred at mean densities exceeding 100/m² and were among nine species occurring in all months of quadrat sampling (Fig 3). Among less common species (Fig. 4) the greatest abundances and numbers of species were observed in late spring and summer months; seasonality in occurrence was particularly marked for *Latreutes parvulus* and *Acanthonyx petiverii*. Because of the larger size of some individuals, *Dardanus fucosus* and *Cronius ruber* were more conspicuous on the reef than suggested by their low abundances.

A density of 248/m² was calculated for decapods from boulders in the areas of loose rock along the transect. All 12 species taken from boulders also occurred in quadrat samples from the reef surface, but the order of abundance differed (Table 1). Predominance of *Pseudomedaeus agassizi* and routinely high numbers of *Petrolisthes galathinus* were characteristic of the boulder substrates; larger individuals of these species were taken from boulders than from fouling mat on the reef surface (Appendix I).

Density of decapods in sediment samples differed markedly between the three areas sampled (Table 2). Decapods numbering 339/m² were found in offshore bottom sediments. *Paguristes hummi*, at 318/m², clearly predominated on this substrate of coarse, shell-fragment sediments. Density of decapods in reef crevice sediments was much lower at 68/m². *Leptochela serratorbita* was most abundant in crevice sediments but occurred in all three sediment areas sampled. The lowest total density of decapods, 25/m², was found in fine sediments of the inshore bottom. Three of the five species found there were also taken in reef crevices and one was also taken from the offshore bottom.

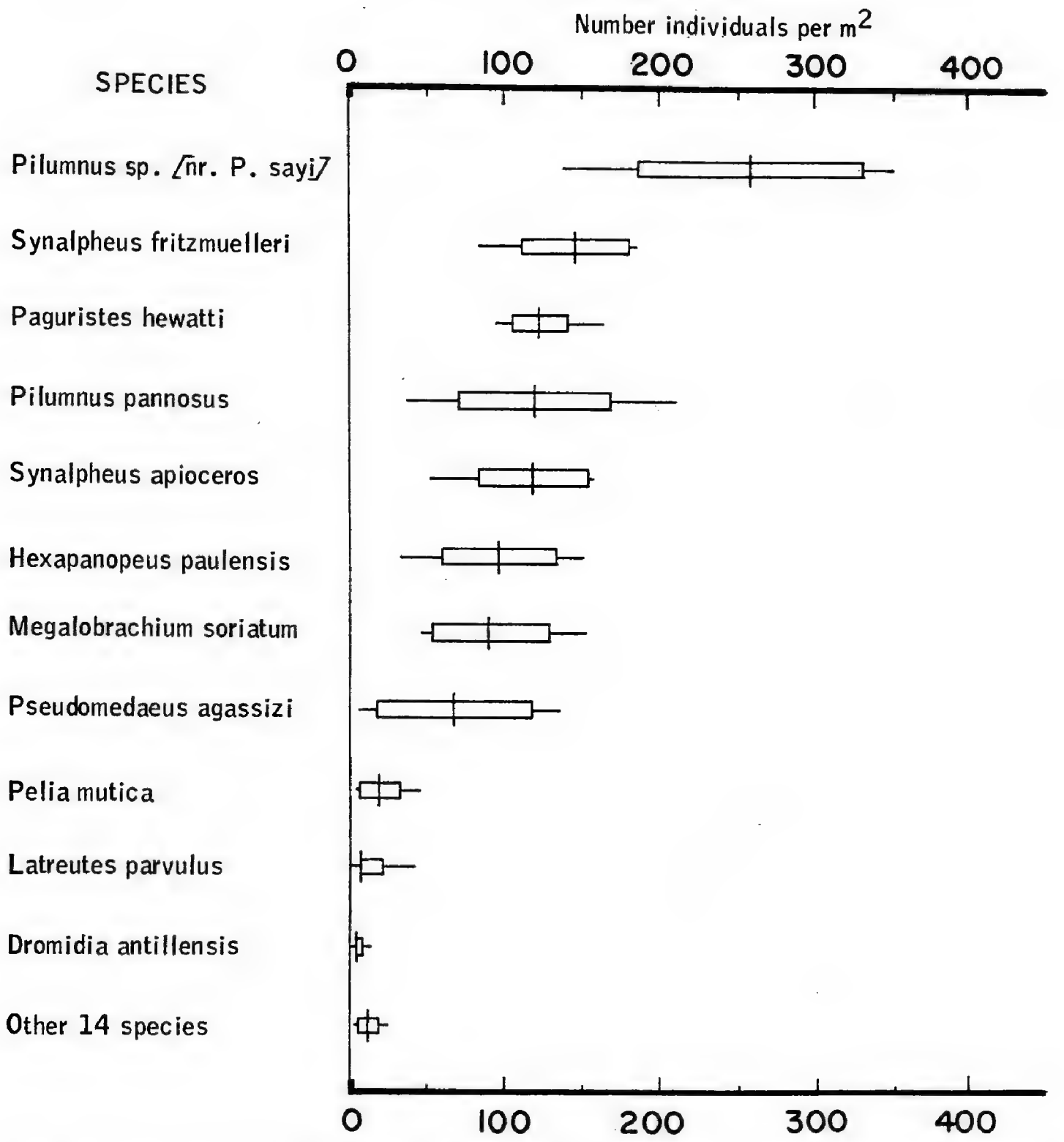

FIG. 3. Densities of decapod crustacean species in quadrat samples from reef surface. Vertical line gives mean, horizontal line gives range, and rectangle gives 95% confidence limits over eight monthly values between August, 1970 and July, 1971.

Diversity of Reef Decapods

Shannon's diversity values ($H' \log_{10}$) ranged from 0.1574 on offshore sediments to 0.9331 on the heavily fouled reef surface (Table 3). A "Transect Overall" diversity of 1.0113 was determined after pooling weighted counts from the transect substrates. The evenness component of diversity was lowest for decapods from offshore sediments (SO) and highest for those from boulder samples. Dominance index was lowest for samples from the largely fouled reef surface (quadrats) and highest for samples from offshore sediments. A highly significant inverse correlation was noted between H′ and DI ($r = -0.9639$; $P < 0.001$).

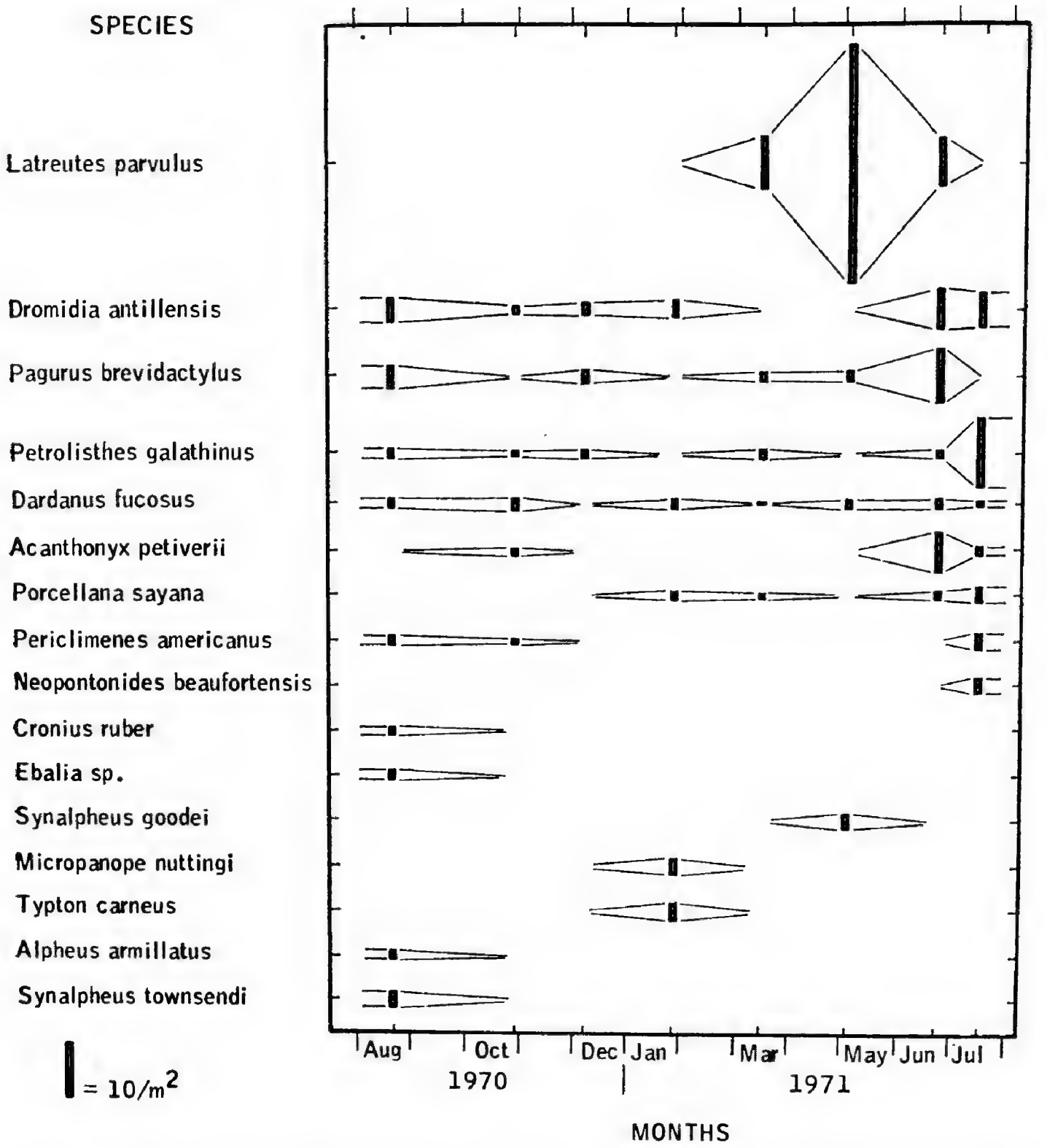

FIG. 4. Occurrence and density of less abundant species showing seasonality of occurrence during eight periods of quadrat sampling from the reef surface.

Lower mean diversity values were obtained for quadrat samples in fall and winter than in spring and summer months. Values of H′ $\log_{10}$ for reef surface quadrat samples ranged from 0.8089 in October, 1970 to 0.9547 in May, 1971. Analysis of variance indicated the effect of months was highly significant ($P < 0.005$). The difference in mean H′ between the three sampling areas on the reef surface (A_1, A_2, and A_3) ranged from 0.8837 in A_1 to 0.8912 in A_3 and was not statistically significant.

Rarefaction diversity curves (Figs. 5 and 6) roughly approximated the relationships observed among values of H′. Rarefaction diversity was, as expected,

TABLE 1

Decapod crustaceans from 22 boulders (41,000 g) collected along study transect from August, 1970 through July, 1971; number of boulders collected per month is given in parentheses (average eroded 1860 g boulder occupied area of 0.0336 m^2).

Species	Number					Total No.	No./m^2
	Aug 70 (6)	Oct 70 (3)	Mar 71 (3)	Jun 71 (5)	Jul 71 (5)		
Pseudomedaeus agassizi	12	6	10	9	23	60	81.9
Hexapanopeus paulensis	4	2	13	5	6	30	40.9
Paguristes hewatti	2	1	1	9	4	17	23.2
Petrolisthes galathinus	6	2	1	3	2	14	19.1
Synalpheus fritzmuelleri	1	0	2	1	10	14	19.1
Pilumnus parnosus	7	2	2	3	0	14	19.1
Pilumnus sp. (nr. *P. sayi*)	4	2	2	1	5	14	19.1
Megalobrachium soriatum	1	2	0	3	6	12	16.4
Synalpheus apioceros	0	0	1	0	2	3	4.1
Pelia mutica	0	0	0	1	1	2	2.7
Neopontonides beaufortensis	0	0	0	0	1	1	1.4
Totals	37	17	32	35	60	181	248.0

TABLE 2

Decapod crustaceans from 42 (14 from each area) one-liter (0.02 m^2 surface area) samples of offshore bottom sediments (SO), sediment deposits within reef crevices (SR), and inshore bottom sediments (SI) along study transect.

Species	SO		SR		SI	
	No./14 l	No./m^2	No./14 l	No./m^2	No./14 l	No./m^2
Paguristes hummi	89	317.7	2	7.1	0	0.0
Leptochela serratorbita	1	3.6	8	28.6	2	7.1
Hexapanopeus paulensis	0	0.0	4	14.3	0	0.0
Pagurus annulipes	0	0.0	1	3.6	2	7.1
Upogebia affinis	3	10.7	0	0.0	0	0.0
Osachila sp. (nr. *O. acuta*)	1	3.6	1	3.6	0	0.0
Synalpheus fritzmuelleri	0	0.0	1	3.6	1	3.6
Cronius ruber (juv.)	1	3.6	0	0.0	0	0.0
Persephona mediterranea	0	0.0	0	0.0	1	3.6
Paguristes hewatti	0	0.0	1	3.6	0	0.0
Petrolisthes galathinus	0	0.0	1	3.6	0	0.0
Portunidae (juv.; not *Cronius*)	0	0.0	0	0.0	1	3.6
Totals	95	339.2	19	68.0	7	25.0

greatest for the "Transect Overall" count. Rarefaction curves for decapods in sediments were truncate and obscure because of the small numbers of individuals collected, but curves for reef crevice sediments (SR) and inshore bottom (SI) clearly trended toward higher diversity than the curve for offshore sediments (SO). Curves for quadrat samples from the three areas (A_1, A_2, and A_3) of the reef surface were very similar; however, rarefaction diversity in area A_2, the

TABLE 3

Comparison of number of species, number of individuals, diversity values (H′ $\log_{10}$), evenness values (J′), and dominance index (DI) for substrates within transect.

Substrate	% of Transect Area	No. Species	No. Individuals	H′ $\log_{10}$	J′	DI
Reef Surface--Quadrats (MT + RW)	60.2	25	6122	0.9331	0.6675	37.93
Rock (Boulder) Samples (RB)	1.5	11	181	0.8705	0.8359	49.73
Sediment:						
Offshore Samples (SO)	17.8	5	95	0.1574	0.2252	94.74
Reef Crevice Samples (SR)	1.9	8	19	0.7401	0.8195	63.16
Inshore Samples (SI)	18.6	5	7	0.4361	0.6239	66.66
Transect Overall (Weighted)	100.0	32	8208	1.0113	0.6719	33.82

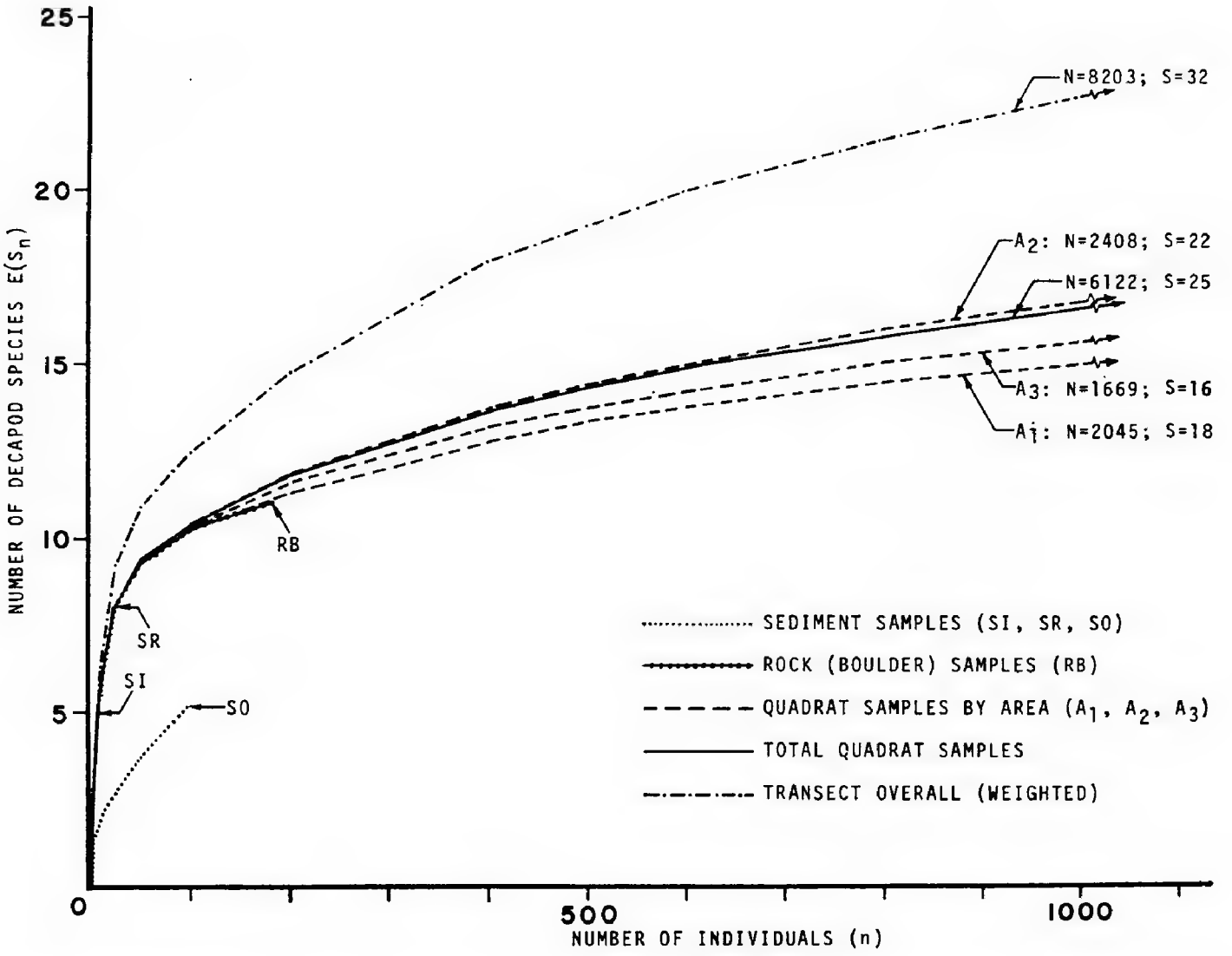

FIG. 5. Rarefaction diversity curves [n vs. $E(S_n)$] comparing reef substrates within study transect. Monthly quadrat samples are pooled for A_1, A_2, A_3, and Total Quadrat Samples.

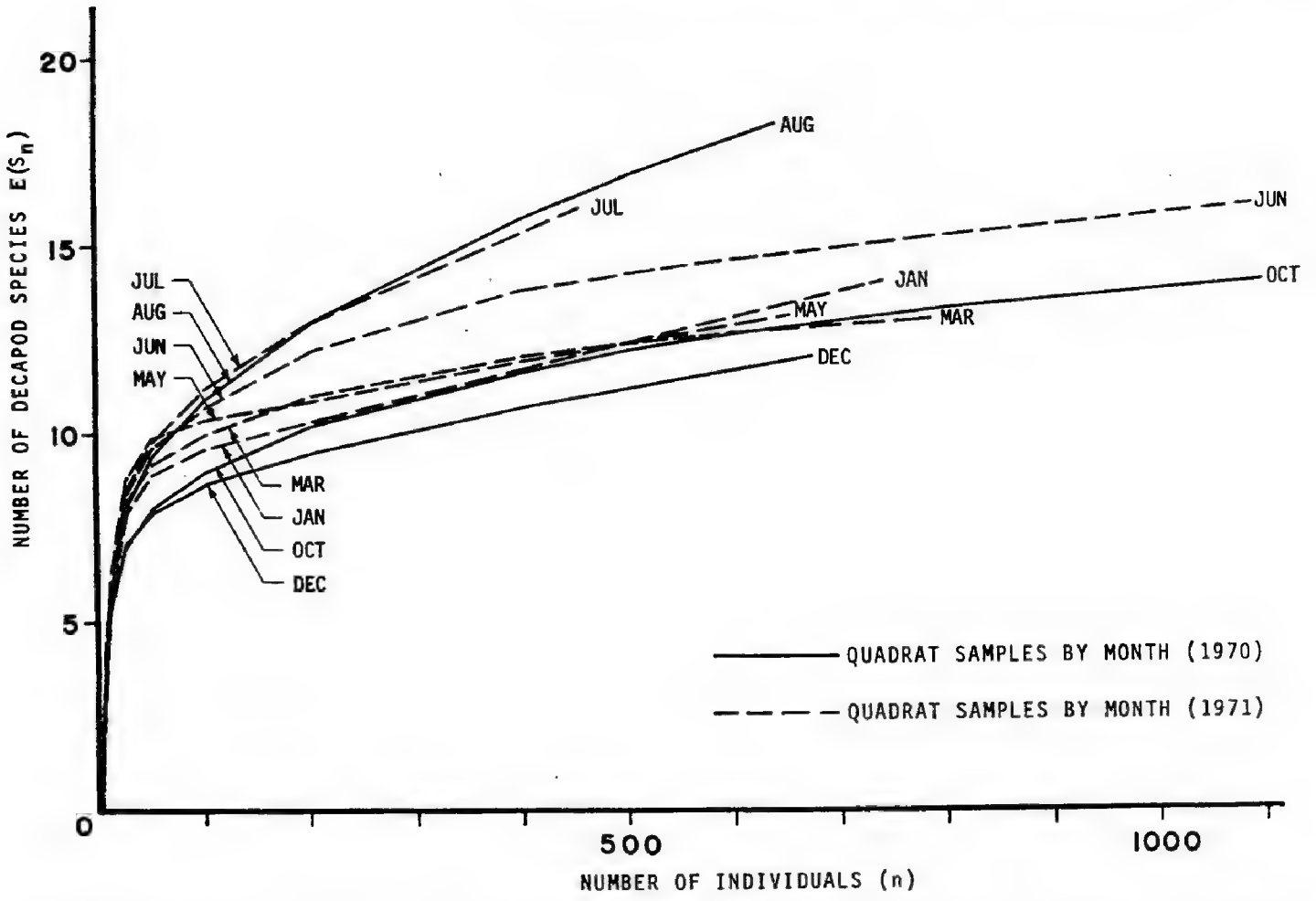

FIG. 6. Rarefaction diversity curves [n vs. $E(S_n)$] comparing monthly quadrat samples from study transect. Quadrat samples from A_1, A_2, and A_3 are pooled for each month.

densely fouled top of the reef, was slightly greater than diversity on the reef slopes.

A pattern of lower diversity in winter quadrat samples was evident among monthly rarefaction curves (Fig. 6) much as among monthly values of H′. Rarefaction curves for June, July, and August were, at all values of n, richer in species than those for October, December, and January. Curves for March and May approached those of summer months at reduced values of n. Only at very low $n(< 50)$ did the curve for May (month of the highest Shannon diversity) reflect a species richness higher than all other months.

DISCUSSION

Level-Bottom Species

Of the decapod species here reported, 20 were taken only from predator stomachs or the water column overlying the reef. Their occurrence was largely confined to stomachs of nektonic fishes which fed on outlying areas of level bottom surrounding the reef (Appendix II). Nineteen of these species and 23 of the 28 reported from level bottom by Hildebrand (1954) have distributions extending into the Carolinas or to the Virginian waters beyond. The frequent occurrence of such species tends to justify inclusion of the northwestern Gulf in the "Carolinian" zoogeographic province (Hedgpeth 1953, Williams 1965), at least on the basis of level-bottom decapods. However, there is little resemblance be-

tween the level-bottom assemblage and the decapod assemblage on the reef. Of the 28 decapods reported from level bottom by Hildebrand (1954), only five of his less abundant species also occurred among the 46 species associated with substrates of Seven and One-half Fathom Reef. As noted by Abele (1974), differences in substrates can easily account for such differences in decapod species composition. Molluscan assemblages on calcareous banks in the northwestern Gulf can also differ dramatically from those of the surrounding level bottom (Parker and Curray 1956, Parker 1960, Tunnell 1973).

Reef Species

Faunal Affinities

The reef decapod assemblage shows less clear-cut Carolinian affinities than northwestern Gulf level-bottom decapod fauna. Of the 46 species taken from reef substrates, 13 are not known from the Carolinas; these are *Synalpheus apioceros*, *Synalpheus goodei*, *Alpheus intrinsecus*, *Alpheus thomasi* (?), *Typton carneus*, *Paguristes hewatti*, *Paguristes hummi*, *Dromia erythropus*, *Osachila* sp. [nr. *O. acuta*], *Acanthonyx*, *petiverii*, *Mithrax acuticornis*, *Pilumnus* sp. [nr. *P. sayi*], and *Platypodiella spectabilis*. Distributions are poorly known for some of these non-Carolinian species, but records suggest that almost all are either widely tropical in distribution or endemic to the Gulf of Mexico. Although some of these species are recorded on the basis of single specimens, others such as *Pilumnus* sp. [nr. *P. sayi*], *Synalpheus apioceros*, *Paguristes hewatti*, and *Paguristes hummi* are among the most abundant species on the reef (Fig. 3, Tables 1 and 2); the abundance of these non-Carolinian species within the study transect accounts for about half the total number of decapods present and illustrates their significance as a component of the reef assemblage. Among these, the hermit crab *Paguristes hewatti*—believed endemic to the western Gulf—is probably the dominant decapod species on the reef when both size and numbers are considered.

Despite its tropical components, the reef decapod fauna bears little resemblance to the distinctly tropical fauna reported by Pequegnat and Ray (1974) from West Flower Garden Bank in the northwestern Gulf of Mexico. Only four of the 49 species reported from West Flower Garden Bank also occurred on Seven and One-half Fathom Reef. The West Flower Garden fauna includes very few of the Carolinian species typical of Seven and One-half Fathom Reef, and, with the exception of the tentatively determined *Synalpheus apioceros* from West Flower Garden Bank, the two areas do not share the tropical component of their respective decapod faunas. The Seven and One-half Fathom Reef fauna more resembles that reported from near Heald Bank on a "coral locality" at 29°50′N, 94°18′W in Hulings' (1955) unpublished master's thesis. The five decapods reported from that substrate included *Synalpheus fritzmuelleri*, *Leptodius agassizii* (=*Pseudomedaeus agassizi*), and *Paguristes* sp. Heald Bank was later listed as the type locality for *Paguristes hewatti* Wass, 1963, a species known only from there, Seven and One-half Fathom Reef, and an area in 8–9 f off Vermilion Bay, Louisiana (Felder 1973b).

The reef decapod fauna was also compared to the decapod assemblage of west-

ern Gulf coastal jetties, but only after supplementing the preliminary list of Texas jetty fauna reported in Whitten, Rosene, and Hedgpeth (1950). Additional collections were made from jetties north and south of the reef, including jetties at Aransas Pass, Corpus Christi Fish Pass, Mansfield Pass and Brazos Santiago. Over 30 intertidal and subtidal decapod species (in authors' collections) were added to the 19 listed by Hedgpeth in Whitten *et al.* (1950). The list in Whitten *et al.* includes few of the subtidal decapods taken in our supplementary collections from Texas jetties. Most of the decapods they reported are of Carolinian affinity, and none of those species was found on Seven and One-half Fathom Reef. Our collections from jetties include 12 species that also occur on the reef; these are *Alpheus intrinsecus*, *Alpheus armillatus*, *Synalpheus fritzmuelleri*, *Lysmata wurdemanni*, *Petrolisthes galathinus*, *Polyonyx gibbesi*, *Dromidia antillensis*, *Acanthonyx petiverii*, *Pelia mutica*, *Cronius ruber*, *Pilumnus pannosus*, and *Pilumnus* sp. [nr. *P. sayi*]. The jetty assemblage shares this large number of species with the reef assemblage, including some species with tropical affinities, but it is distinct in including abundant shallow-water Carolinian species and its own tropical components such as *Panopeus bermudensis* Benedict and Rathbun 1891, *Pachygrapsus gracilis* (Saussure 1858), and *Cyclograspsus integer* H. Milne Edwards 1837. The greatest resemblance to decapod fauna of the reef is found among fouling accumulations on the submerged ends of the more southerly jetties visited, but even here the sparse epifaunal fouling mat does not support the abundance of individuals found on Seven and One-half Fathom Reef.

Parker (1960) did not include decapods in the characterization of his northern Gulf "Calcareous Bank Assemblage." However, the difference in the depth and origin of waters bathing various calcareous reefs in the northwestern Gulf—coupled with variations in the origin and nature of the bank substrates—should account for great variation in associated decapod assemblages. Whenever the base substrate of a bank is covered by a persistent encrusting epifauna or surface bioherm, the nature and quantity of that habitat is an important determinant of the associated decapod fauna. Dominant decapod taxa in the resultant biotope are usually specialized morphologically to use such biohermal substrates for shelter, as a feeding site, or as a source of nutrition (Abele 1974; Gore, Scotto, and Becker 1978). The Seven and One-half Fathom Reef decapod assemblage is predominated by shallow-water species associated with the fouling mat of *Phyllochaetropterus* tubes, sponges, ascidians, and hydroids on the reef surface; it might best be labeled as part of a Shallow Sublittoral Fouling Assemblage and recognized by the decapod species and order of abundance here reported from the reef surface (Figs. 3 and 4). As the predominant component of the reef fouling mat, the polychaete *Phyllochaetopterus* may by its distribution greatly determine the distribution of the associated decapod assemblage. Studies of decapods on intertidal polychaete bioherms, such as sabellariid worm reefs (Gore *et al.* 1978), suggest that at least the more common decapod species are ecologically and zoogeographically reliant on the polychaete biotope. The vertical and geographical distribution of *Phyllochaetopterus* accumulations is, however, poorly

known at present, and a specific relationship between *Phyllochaetopterus* and the associated decapods has yet to be illustrated.

Temperature and salinity regimes (Fig. 7) and currents bathing the reef (Fig. 1) are likewise important, interrelated determinants of the assemblage. Seasonal changes in the point of convergence for northerly and southerly longshore currents off the Texas Coast (Hedgpeth 1953, Watson and Behrens 1970) appear to affect physical parameters (Fig. 7) and presumably the supply of immigrants (larvae) on the reef. Drift data, reviewed by Watson and Behrens (1970),

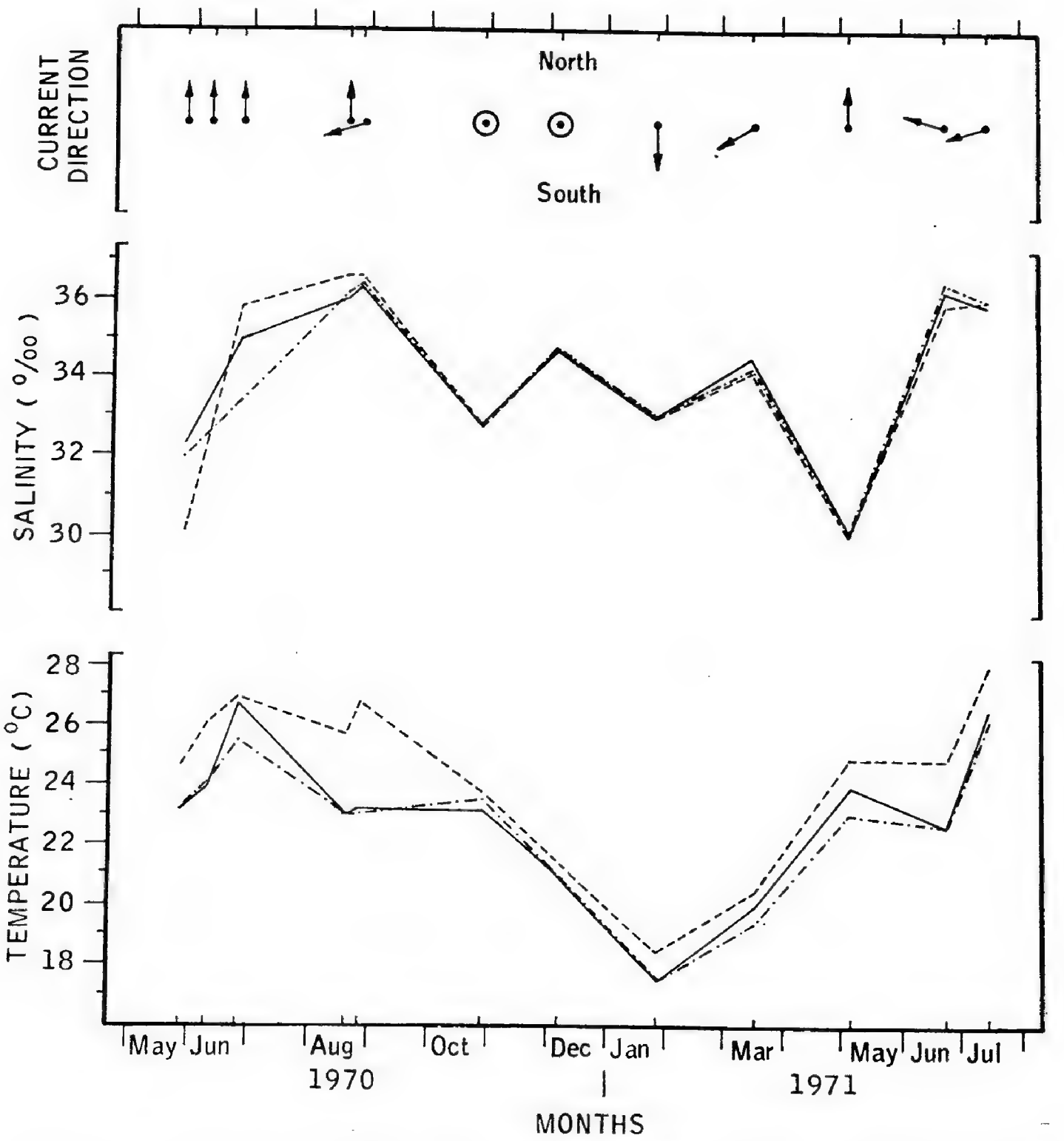

FIG. 7. Water temperature, salinity and surface current direction recorded at Seven and One-half Fathom Reef on sampling dates in 1970 and 1971. Circles replace current vectors on dates when no surface drift was detected. Water temperatures and salinities are given for water surface (– – – – – – – –), top of reef (————————), and inshore bottom of reef (– · – · – · –).

indicate that a net annual node of converging currents is located on central Padre Island near Seven and One-half Fathom Reef; coastal waters bathing the reef originate from the more tropical southwestern Gulf in summer and from the northern Gulf in winter. It is then not surprising that the decapod fauna of the reef and South Texas jetties appears to be zoogeographically transitional, especially when the abundance of tropical and Gulf-endemic species is considered. Future delineation of zoogeographical boundaries might best incorporate the documented existence of a permanent, distinctly tropical fauna on the outer Texas shelf (Parker and Curray 1956, Pequegnat and Ray 1974, Briggs 1974) and an area with a seasonally influenced, transitional fauna inshore of it. A similar situation exists below Cape Hatteras (Cerame-Vivas and Gray 1966) where the boundary between coooler northern waters and warmer southern waters results primarily from water circulation and not latitude.

Abundance

Abundance of sublittoral epifauna is seldom treated because of difficulties in sampling. However, the use of SCUBA has greatly facilitated quantitative sampling of sublittoral epifauna (Pequegnat 1964, Ledoyer 1966). Pequegnat has called attention to the high population density and number of species on shallow sublittoral reefs. The mean density he reported for the most abundant decapod on a California siltstone reef, *Paraxanthias taylori* at 570/m^2 on the "Reef top," is reminiscent of the high densities on the upper surfaces of Seven and One-half Fathom Reef. On both the siltstone reef and Seven and One-half Fathom Reef, the greatest densities of decapods occur on the upper surfaces where encrusting or fouling epifauna is most concentrated. For example, the 248 decapods/m^2 on unfouled boulders of Seven and One-half Fathom Reef do not approach the mean of 909/m^2 reported from the reef surface. Densities on boulders would likely be still lower were it not for the extensive erosion of boulder surfaces which increased inhabitable surface area.

The presence of a dense encrusting epifauna, which provides both cover and increased surface area to support high densities of decapods, is dependent at least in part upon the presence of an erodable rock surface to which fouling organisms can attach. Accumulations of epifauna on sublittoral granite rocks at the outer edges of Texas coastal jetties do not approach the thickness or density of those on Seven and One-half Fathom Reef and do not support as dense a decapod fauna. Pequegnat (1964) similarly noted that epifaunal populations on basaltic reefs were well below those on adjacent siltstone reefs. However, he also emphasized the importance of wave-generated movement of water across the top of the reefs as these provide fresh supplies of food and oxygen. Such pulsatile movements were conspicuous at the top of Seven and One-half Fathom Reef where they favored greater development of the epifaunal fouling mat.

Densities of decapods in and on reef sediments may relate to both water movement and sediment composition, which are themselves related. The highest density of sediment-dwelling decapods was found in the coarse, shell-fragment sub-

strate of the offshore bottom where turbulence from the passage of waves was frequently sufficient to displace shell materials. The predominance of *Paguristes hummi* on the offshore bottom singularly accounts for that area's higher density of decapods. The lowest density was found in finer inshore bottom sediments. Although complete sediment analyses were not conducted, shell fragments retained by a 1.19-mm sieve constituted > 55% of samples from offshore bottom, 10–12% of samples from reef crevices, and < 10% of samples from the inshore bottom.

Diversity

A community with high species diversity is often considered high in entropy, uncertainty, complexity, stability, maturity, biological accommodation, or several of these qualities (MacArthur 1955, Margalef 1963, Leigh 1965, Sanders 1968). Such ambiguity seems inevitable when interpreting a statistic in which two independent variables, species richness and evenness (Pielou 1969), are confounded. Since the utility of such classical diversity indices is questionable (Hurlbert 1971, Goodman 1975, Peet 1975), species composition parameters are measured by more than one method in the present study. However, H′ is included to facilitate heuristic comparisons with previously published studies.

Most benthic diversity studies concern other or more inclusive taxocenes than decapod crustaceans and are not comparable to present findings. However, Abele (1974) reported decapod diversity and richness on a variety of marine habitats and related diversity to the number of substrates on each. Diversity on these habitats can be compared to that on Seven and One-half Fathom Reef when the reef Transect Overall count (which encompasses all substrates) is analyzed. Overall counts from the reef habitat included 32 species or two less than Abele reported from the northeastern Gulf jetty habitat. Fewer species and lower evenness account for lower diversity on the reef than on the jetty habitat. However, as previously noted, the weighting procedure may have biased the "Transect Overall" diversity to a slightly lower value than actually exists (see Interpretation of Quantiative Data); the overall decapod diversity on Seven and One-half Fathom Reef thus ranks about as high as that reported by Abele from mangrove communities with four substrates and slightly less than that he reported from rock jetties with five substrates. If Abele's criteria are used to distinguish "substrates," crevice sediments and inshore sediments probably would not be considered separately; similar to rock jetties, the reef then includes five identifiable substrates.

The decapod fauna of the reef is subject to dynamics of immigration and extinction in much the way that MacArthur (1965) describes these factors to affect island species diversity (although pelagic decapod larvae likely account for some differences). If one assumes that the number of species on the reef surface corresponds to its capacity—which is likely after even a brief period of colonization on a small, single habitat (Simberloff and Wilson 1969, Strong 1974)—there must exist a high rate of extinction in equilibrium with immigration. A high ex-

tinction rate should be expected on Seven and One-half Fathom Reef where there is marked seasonal fluctuation in current patterns, salinity and temperature (Fig. 7); this may explain the brief appearance (single specimens) of a number of "immigrant" species during the study. Environmental changes, which potentially affect decapod reproduction, larval recruitment, immigration, survival and extinction, could also account for the observed seasonal fluctuations in diversity and richness. In fact, lack of environmental constancy may result in higher, overall-species richness on the reef than in similar habitats which are environmentally more stable. Abele (1976a) reported such an effect in comparing decapods of differentially disturbed coral reef communities.

Comparison of species diversity and richness across "substrates" (*sensu* Abele 1974, 1976b) of the reef (Table 3, Fig. 5) indicates higher diversity and richness for benthic decapods on rocky substrates than for those of sediments; particularly low diversity and high dominance is found in offshore-bottom, shell-fragment sediments. According to the once popular stability-diversity hypothesis, benthos on shifting bottom is expected to be less stable and less mature than that on hard substrates and is characteristically of lower diversity (Margalef 1968). Johnson (1970) notes that physical perturbations like storms may initiate regressive trends toward lower community grades in such areas. The sediment-dwelling decapods would thus seem to be a more "physically controlled" rather than "biologically accommodated" assemblage using the terms of Sanders (1968). However, all communities are in reality mixtures of the physically controlled and biologically accommodated extremes. For example, the dominance of *Paguristes hummi* and *Leptochela serratorbita* in sediments may reflect a biological specialization for these physically less stable substrates.

The low diversity values for sediment substrates of the reef compare most closely with those reported from the single-substrate sandy beach "habitat" by Abele (1974, 1976b). Reef sediments and sandy beaches are both more homogeneous than are rock substrates which have become fouled by epifauna. The sediment substrate appears to be dominated by a few specialists and has a vertical dimension which is limited to occupation by burrowers, most of which are dependent upon surface contact for food and respiration. By comparison, the vertical dimension on fouled rock surfaces consists of eroded depressions and various subunits of the epifaunal mat—*Phyllochaetopterus* tubes, sponges, ascidians, hydroids, etc.—all of which are accessible to motile benthos. Hence, the variety of resources available on fouled rock surfaces should be conducive to the development of a more diverse assemblage of generalist and specialist decapod species.

Subunit differences between substrates on Seven and One-half Fathom Reef may thus explain differences in diversity between substrates. In other words, certain substrates more broadly fill the general trophic and physiological requirements of the decapod taxocene. The biological niche clearly has more dimensions than can be described by the texture, grain size, and dominant biotic components that are typically used to distinguish a substrate. However, enumeration of (and measurement of diversity within) finer subdivisions of substrates, while

desirable, was beyond the scope of the present study and only increased the difficulty of measurement when attempted by Abele (1974).

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APPENDIX I

Decapod Crustaceans Collected from Seven and One-half Fathom Reef, Texas

References following species cite selected descriptions, illustrations, habitat notes, or recent systematic revisions. Asterisk (*) indicates species not known from the Texas coast prior to this study. Sources of collection are abbreviated in order of frequency and follow key at end of table. Months of collection are followed by year in parentheses and are italicized when collection included ovigerous females. Measurements are given in millimeters at TL (total length, rostrum to telson), SL (carapace shield length), or CW (greatest width of carapace); when $\bar{X}$ (mean) and R (range) of measurements are given, the number measured is given in parentheses and represents all measurable individuals or the total of subsamples taken from all monthly collections.

Suborder: Natantia

FAMILY: Penaeidae

***Penaeus aztecus aztecus* Ives.**—Pérez Farfante 1969:527. rnF, onF. Jun (70). TL = 125. One specimen measurable.

***Trachypenaeus* sp [mostly juvenile *T. similis*].**—Burkenroad 1934:96–102.—Chace 1972:9. rnF. Jun (70); Jun (71). Most specimens mutilated.

FAMILY: Sicyoniidae

***Sicyonia brevirostris* Stimpson.**—Williams 1965:35.—Chace 1972:11.—Cobb, Futch, and Camp 1973. onF. Jun (70). TL = 82.0. One specimen collected.

***Sicyonia dorsalis* Kingsley.**—Williams 1965:37.—Chace 1972:11. onF, rnF. Jun (70). TL = 56.0, 57.0. Three collected; two measurable.

FAMILY: Sergestidae

***Acetes americanus* Ortmann.**—Williams 1965:39.—Chace 1972:12. rnF. Oct, Dec (70). TL = 13.0.One male measured.

Lucifer faxoni Borradaile.—Bowman and McCain 1967:660–671. rbF. Sep (68). Found in only one *Serranus subligarius* which contained 89 individuals (not measured).

FAMILY: Pasiphaeidae

****Leptochela serratorbita* Bate.**—Williams 1965:41.—Chace 1972:16. SR, SI, SO, rbF, rnF. *Jun* (70); Jun, Jul (71). TL$\bar{X}$ = 14.0(8); R = 6.0–17.0.

FAMILY: Palaemonidae

***Neopontonides beaufortensis* (Borradaile).**—Holthuis 1951:190.—Williams 1965: 49. RB, MT. *Jul* (71). TL = 7.5. One measurable; one taken on *Leptogorgia.*

****Periclimenes americanus* (Kingsley).**—Holthuis 1951:60.—Williams 1965:43.—Chace 1972: 31. MT, UK. *Jul, Aug* (68); *Aug*, Oct (70); Jul (71); Jul (73). TL$\bar{X}$ = 12.8(5); R =7.5–19.0. Five measurable specimens; Aug (68) specimens taken among empty gastropod shells.

****Typton carneus* Holthuis.**—Chace 1972:46. MT Jan (71). TL = 8.5. One mutilated specimen.

FAMILY: Alpheidae

****Alpheus intrinsecus* Bate.**—Crosnier and Forest 1966:286.—Chace 1972:68. UK. Aug (68). TL = 22.0. Ovigerous females taken at Port Aransas, Texas jetties Aug (72).

***Alpheus floridanus* Kingsley.**—Crosnier and Forest 1966:267.—Chace 1972:65. SR. Aug (68). TL = 23.5. Single specimen collected in mud sample from reef crevice.

***Alpheus thomasi* (?)** [*A. thomasi* Hendrix and Gore, 1973:413]. MT Aug (72). TL = 15.0. Species determination tentative for single mutilated specimen.

***Alpheus armillatus* H. Milne Edwards.**—Williams 1965:67.—Chace 1972:62. MT. Aug (70). Reef specimen mutilated; two others (clearly *A. armillatus*) were taken from nearby Port Aransas jetties Aug (72).

***Synalpheus fritzmuelleri* Coutière.**—Williams 1965:69.—Chace 1972:92. MT, RB, SI, SR, rbF. *All* months. $TL\bar{X} = 10.7(400)$; R = 4.0–19.5. Abundant in fouling mat; $TL\bar{X}$ from 50 measured each of eight collection months.

***Synalpheus apioceros* Coutière,** 1909:27.—Chace 1972:86. MT, RB, rbF. *All* months. $TL\bar{X} = 10.8(400)$; R = 4.5–16.0. Abundant in fouling mat; $TL\bar{X}$ from 50 measured each of eight collection months.

***Synalpheus goodei* Coutière,** 1909:58.—Chace 1972:93. MT. May (71). TL = 7.5. One specimen taken.

***Synalpheus twonsendi* Coutièr,** 1909:32.—Williams 1965:72.—Chace 1972:104. MT. Aug (70). TL = 9.3, 12.2. Two specimens taken.

FAMILY: Ogyrididae

***Ogyrides limicola* Williams.**—Williams 1965:74. rnF. May (70); Jun (71). Chace (1972) suggests this species may be identical with *O. yaquiensis*.

FAMILY: Hippolytidae

***Lysmata wurdemanni* (Gibbes).**—Williams 1965:84.—Chace 1972:129. MT, UK, rbF. *Aug, Sep* (68); Jul (73). TL = 10.5, 19.0, 32.0. Common on jetties at Port Aransas, Texas in May, Jun, Jul (71); many ovigerous on jetties Aug (72).

***Latreutes parvulus* (Stimpson).**—Williams 1965:79. MT. Mar, *May*, Jun (71). $TL\bar{X} = 11.4$ (23); R = 5.0–12.5. Most abundant in May (71).

Suborder: Reptantia

FAMILY: Scyllaridae

***Scyllarides nodifer* (Stimpson).**—Williams 1965:98.—Lyons 1970:7. SO. Mar (71) trawled; Aug. (73) exuvium. CL = 51.0 (of exuvium). Exuvium from SO.

FAMILY: Upogebiidae

***Upogebia affinis* (Say).**—Williams 1965:103–104.—Thistle 1973:1–23. SO. Jun (71). TL = 16.0. Least mutilated individual measured.

FAMILY: Porcellanidae

***Polyonyx gibbesi* Haig.**—Williams 1965:113. CM. *Aug* (73). CW ~13.0. CM with *Chaetopterus variopedatus*; also taken near jetties at Mansfield Channel and Port Aransas, Texas.

***Megalobrachium soriatum* (Say).**—Williams 1965:112. MT, RB, rbF. *All* months. $CW\bar{X} = 3.9(120)$; R = 1.5–6.0. Abundant in MT throughout study.

***Petrolisthes galathinus* (Bosc).**—Williams 1965:107. RB, MT, SR, rbF. All (70); Mar, Jun. Jul (71); Jul (73). $CW\bar{X} = 7.6(12)$; R = 3.0–12.0. Larger individuals (CW = 7.0–12.0) taken on RB; smaller from MT.

***Porcellana sayana* (Leach).**—Williams 1965:110. MT, CM. Jul (70); Jan, *Mar*, Jun, Jul (71); Aug (72). $CW\bar{X} = 5.5(8)$; R = 2.6–7.5. Taken both free-living and commensal with *Dardanus fucosus* or *Petrochirus diogenes*.

FAMILY: Paguridae

***Pagurus brevidactylus* (Stimpson).**—McLaughlin 1975:360. MT. *Jun*, Aug, Dec (70); *Mar*, May, *Jun* (71); Aug (72). $SL\bar{X} = 1.5(13)$; R = 1.2–2.1. McLaughlin (1975) concludes that *P. miamensis* is a junior subjective synonym of this species.

***Pagurus annulipes* (?) Say.**—Felder 1973b:26. SI, SR. Jul (71). SL = 1.5, 1.5, 2.0. Poor condition of these three specimens and confusion in literature prohibit clear distinction of this material from *P. criniticornis* and *P. stimpsoni* at present. McLaughlin (1975) suggests that the Gulf species formerly referred to *P. annulipes* may be *P. stimpsoni.*

***Pagurus impressus* (Benedict).**—Provenzano 1959:399.—Williams 1965:129. rnF. Oct (70). One mutilated specimen from rnF; live individuals were collected from surf on adjacent Padre Island Aug (72).

***Pagurus pollicaris* Say.**—Provenzano 1959:401.—Williams 1965:128. rbF. Oct (70). SL = 4.0, 4.2, 4.5, 4.5. Specimens from rbF were within shells of *Cantharus cancellarius*, a gastropod found only on SI.

FAMILY: Diogenidae

***Petrochirus diogenes* (Linnaeus).**—[under *P. bahamensis*] Provenzano 1959:378.—[under *P diogenes*] Williams 1965:122. rnF. Jun, Aug (70). SL = 3.0, 4.0, 4.5. Much larger individuals were seen in catch by trawler Mar (71) from just off reef.

***Dardanus fucosus* Biffar and Provenzano,** 1972:782. MT, SR, RW, rnF. All months; *Aug* (72). $SL\bar{X} = 8.6(18)$; R = 2.5–15.0. Smaller in MT than on SR and RW; few checked for presence of eggs.

***Paguristes hummi* Wass,** 1955:148.—Felder 1973b:31. SO, SR. Jun, Aug (70); May, *Jun,* Jul (71). $SL\bar{X} = 2.3(25)$; R = 1.5–4.5. "Dates collected" reflect dates for sampling of SO where *P. hummi* predominated.

***Paguristes hewatti* Wass,** 1963:133.—Felder 1973b:31.—McLaughlin and Provenzano 1974: 198. MT, RW, RB, SR, rbF, rnF. All months; *Jul* (68); *Jun* (70); *May, Jun, Jul* (71); *Jul* (73). $SL\bar{X} = 4.7(90)$; R = 1.5–7.7. $SL\bar{X}$ in MT ~ 3.0; $SL\bar{X}$ in RW ~ 5.5; perhaps the most conspicuous species of decapod on reef, considering size and numbers; the bopyrid isopod *Stegias* sp. was taken from abdomens of several individuals in Aug. (70).

FAMILY: Albuneidae

***Albunea paretii* Guérin.**—Williams 1965:137. rnF. Jun, Aug, Oct, Dec (70). Fragments from *Lutjanus campechanus* stomachs on most 1970 collection dates.

FAMILY: Leucosiidae

***Ebalia* sp.**—Felder 1973b:39. MT. Aug (70). CW = 3.0. One juvenile male (possibly *E. cariosa*) collected; first record of this genus from the NW Gulf.

***Persephona mediterranea* (Herbst).**—[under *P. Panctata aquilonaris*] Williams 1965:150. [under *P. aquilonaris*] Guinot Dumortier 1959:429.—Felder 1973b:42. SI, rnF. Aug (68); Aug (70); Jun (71). CW = 4.0. One taken June (71) from SI (measured); others from rnF; Abele (1970) explains recognition of *P. mediterranea* (Herbst) as senior synonym.

FAMILY: Calappidae

***Osachia* (?) sp. [nr. *O. acuta* (?)].**—Felder 1973b:43. SR, SO. Jun (70); Jun (71). CW = 3.0, 3.0. Present material consists of two poorly preserved immature male tentatively determined by H. B. Roberts. Two juvenile males; first record of this genus from the NW Gulf.

***Hepatus epheliticus* (Linnaeus).**—Williams 1965:158. UK, rnF, rbF. Apr, Jun, Dec (70). CW = 54.0. Carapace fragments on reef in Apr and Jun; in rnF and rbF in Dec.

***Hepatus pudibundus* (Herbst).**—Williams 1965:157. rnF. Oct (70). All three specimens taken from *Lutjanus campechanus.*

FAMILY: Dromiidae

***Dromia erythropus* (George Edwards).**—Rathbun 1937:31.—Forest 1974:80. UK (MT or RW). Jul (68); Apr (69). CW = 60.0, 73.5. A specimen has also been taken from off Louisiana (Felder, 1973b).

***Dromidia antillensis* Stimpson.**—Williams 1965:142.—Felder 1973b:44. MT, RW, rbF. *Jun,* Aug, Oct, Dec (70); Jan, Jun, Jul (71); *Aug* (72). $CW\bar{X} = 8.6(18)$; R = 4.0–22.0. Small ones common in MT; all carried cover of compound ascidians.

FAMILY: Parthenopidae

Heterocrypta granulata (Gibbes).—Williams 1965:270.—Felder 1973b:45. SO, rnF. Aug (68); Aug (72). Cheliped in rnF Aug (68); one mutilated specimen taken from SO Aug (72).

***Parthenope serrata* (H. Milne Edwards).**—Williams 1965:267. Felder 1973b:45. rnF. Aug (70). Fragments of one individual from *Lutjanus campechanus.*

FAMILY: Majidae

***Stenorhynchus seticornis* (Herbst).**—Williams 1965:244.—Felder 1973b:48. RW, MT. Jun (68); Apr (69); *May*, *Jun*, Aug, Oct (70). $CW\bar{X} = 10.2(8)$; R = 8.0–14.0. Most common Jun (70); none after Oct (70); usually on crevice walls, pairing of males and females observed Jun (70). Yang (1976) notes that two species are probably confused under the name *S. seticornis.*

***Acanthonyx petiverii* H. Milne Edwards.**—Garth 1958:223.—Felder 1973b:53. MT. *Oct* (70); Jun, Jul (71). $CW\bar{X} = 3.0(8)$; R = 1.5–6.0. After ovigerous (CW = 5.0, 6.0) in Oct none taken until five juveniles (CW = 1.5–2.5) in Jun and one (CW = 3.0) in Jul.

****Pelia mutica* (Gibbes).**—Williams 1965:250.—Felder 1973b:53. MT, RB, rbF. *All* months. $CW\bar{X} = 5.3(65)$; R = 2.5–10.0. Common in MT throughout study.

****Mithrax acuticornis* Stimpson.**—Rathbun 1925:388–391.—Felder 1973b:52. UK (MT or RW). Sep (68). CW = 18.0. A specimen has also been taken off Galveston, Texas (Felder 1973b).

***Libinia* sp. (fragments).** rnF. Dec (70). Probably *L. dubia* H. Milne Edwards or *L. emarginata* Leach; mutilated.

****Macrocoeloma trispinosum nodipes* (Desbonne).**—Rathbun 1925:468.—[under *M. trispinosum* (Latreille)] Felder 1973b:53. UK. *Jul* (68). CW = 34.0. Single specimen shares some characters with *M. t. nodipes* and second variety of *M. trispinosum* discussed by Rathbun (1925).

***Stenocionops furcata coelata* (A. Milne Edwards).**—Williams 1965:261. MT. Jul (73). CW = 16.2. Single specimen taken near shallowest point of reef.

FAMILY: Portunidae

***Ovalipes floridanus* Hay and Shore.**—Williams 1976:205–208. SO, rnF. May, Jun, Jul Aug (70); Aug (73). CW = 24.5. Same as *O. ocellatus floridanus* of Türkay (1971) and *O. guadulpensis* of Felder 1973b); CW for single specimen dredged Aug (73); others from rnF.

***Cornius ruber* (Lamarck).**—Williams 1965:174. RL, MT. SO, SI. Jul (68); Jun, Aug (70); May, Jul (71); Aug (72); May, Aug (73). $CW\bar{X} = 35.0(10)$; R = 5.5–71.0. Smaller individuals (CW = 5.5–7.5) in MT, SO, and SI than in RL (CW = 47.5–71.0).

***Arenaeus cribrarius* (Lamarck).**—Williams 1965:173. onF. Jun (70). Fragments of one individual in stomach of *Rachycentron canadum.*

***Callinectes sapidus* Rathbun.**—Williams 1974:778. WC, rnF, SI? Aug (70); May (73). Two carapaces collected from SI Aug (70); drifting with current May (73).

***Callinectes similis* Williams,** 1966:87.—Williams 1974:731. WC, rnF, onF, rbF. Jul (68); May, Jun, Aug, Dec (70). $CW\bar{X} = 57.0(8)$; R = 44.0–71.0. Common Jun (70) both in WC and predator stomachs; many drifting with current May (73).

***Portunus gebbesii* (Stimpson).**—Williams 1965:164. rnF, onF. Jun (70).CW = 49.0. Measured specimen from large *Rachycentron canadum.*

FAMILY: Xanthidae

****Pilumnus* sp. [nr. *P. sayi* Rathbun].**—[*P. sayi*] Williams 1965:177.—[under *P. sayi* (part) and *P. dasypodus* (part)] Felder 1973b:61. MT, RB, rbF. All months; *Jun*, *Aug* (70); *Mar*, *May*, *Jun*, *Jul* (71);*Aug* (72). $CW\bar{X} = 5.6$ (120); R = 1.5–14.0. Possibly a *P. sayi* ecomorph; systematic studies of this genus are in progress; abundant in MT throughout study; found in most rbF species examined; none in rnF or onF.

***Pilumnus pannosus* Rathbun.**—Williams 1965:181.—Felder 1973b:64. MT, RB, rbF. All months; *Aug* (70); *Jul* (71); *Aug* (72); *Jul* (73). CWX = 4.7 (120); R = 1.5–18.0. Abundant in MT throughout study; found in four species of rbF; none in rnF or onF.

***Glyptoxanthus erosus* (Stimpson).**—Williams 1965:185.—Felder 1973b:60. UK. Oct (68); sighting May (73). CW = 79.0. Measured specimen only one collected; another sighted *in situ* May (73).

****Platypodiella spectabilis* (Herbst).**—Guinot 1967:562.—Felder 1973b:65—[under *Platypodia spectabilis*] Rathbun 1925:247. MT. Apr (70). CW = 18.5. One female taken from beneath compound ascidian, *Didemnum* sp.

****Pseudomedaeus agassizi* (A. Milne Edwards).**—[under *Leptodius agassizii*] Williams 1965: 192.—[under *Pseudomedaeus agassizi*] Guinot 1967:726.—Felder 1973b:67. RB, MT, rbF. All months; *Dec* (70); *Mar* (71). CWX = 4.8(60); R = 2.0–10.0. Usually larger individuals (CW = 6.0–10.0) on RB and in stomachs than in MT (CW = 1.5–5.5).

****Hexapanopeus paulensis* Rathbun.**—Williams 1965:189.—Felder 1973b:70. MT, RB, SR. All months. $CW\bar{X}$ = 1.5–9.0. Few adult females found, none ovigerous; abundant in MT throughout study.

****Micropanope nuttingi* Rathbun.**—Williams 1965:194.—Felder 1973b:66. MT. Jun (70); Jan (71); Jul (73). $CW\bar{X}$ = 4.3(6); R = 3.2–5.2. Easily confused with small *H. paulensis*; *M. scultipes*" cited from off Port Mansfield, Texas (Felder 1973b) is also *M. nuttingi*.

FAMILY: Pinnotheridae

****Pinnixa lunzi* Glassell.**—Williams 1965:214.—Felder 1973b:71. rnF, CM? Jun (70). CW = 11.7. Previously discussed by Felder (1973a); likely a facultative commensal.

Sources of Collections.—SEDIMENTS: SI = on inshore bottom, SR = in reef crevices, SO = on offshore bottom.—ROCK SUBSTRATES: RB = loose boulders, RW = reef surface without MT, RL = rocky holes in reef or beneath ledges.—STOMACHS: rbF = resident benthic fish, rnF = resident nektonic fish, onF = occasional nektonic fish.—OTHER: MT = epifaunal fouling mat, CM = commensal, WC = water column, UK = unknown.

APPENDIX II

Crustacean Species in Fish Stomachs from Seven and One-half Fathom Reef

Crustacean species are indented beneath fish species; number in parentheses indicates total number of individuals removed from respective fish species and % indicates frequency of occurrence among stomachs containing food. Proportion below fish species name is number stomachs with food/number examined.

RESIDENT BENTHIC FISH

Epinephelus adsecensionis (Osbeck)
7/8
- *Pilumnus* sp. [nr. *P. sayi*] (5) 42.9%
- *Pseudomedaeus agassizi* (3) 28.6
- *Hexapanopeus paulensis* (1) 14.3
- *Paguristes hewatti* (1) 14.3
- *Synalpheus fritzmuelleri* (1) 14.3

Halichoeres bivittatus (Bloch)
3/3
- *Megalobrachium soriatum* (1) 33.3%
- *Pilumnus* sp. [nr. *P. sayi*] (1) 33.3
- *Xanthidae* (1) 33.3

Halichoeres caudalis (Poey)
4/5
- *Pilumnus* sp. [nr. *P. sayi*] (1) 25.0%

Mycteroperca rubra (Bloch)
4/5
- *Leptochela serratorbita* (1) 25.0%

Odontoscion dentex (Cuvier)
3/4
- *Leptochela serratorbita* (1) 33.3%

Opsanus pardus Goode & Bean
10/10
- *Paguristes hewatti* (6) 30.0%
- *Pagurus pollicaris* (4) 10.0
- *Callinectes similis* (1) 10.0
- *Dromidia antillensis* (1) 10.0
- *Hepatus epheliticus* (1) 10.0
- *Pelia mutica* (1) 10.0
- *Pilumnus* sp. [nr. *P. sayi*] (1) 10.0

Pareques acuminatus (Bloch & Schneider)
8/10
- *Pilumnus* sp. [nr. *P. sayi*] (5) 62.5%
- *Synalpheus fritzmuelleri* (3) 37.5
- *Hexapanopeus paulensis* (2) 25.0
- *Pseudomedaeus agassizi* (1) 12.5
- *Petrolisthes galathinus* (1) 12.5
- *Pilumnus pannosus* (1) 12.5
- Ispoda (1) 12.5

Pomacentrus variabilis (Castelnau)
4/4
- None

Rypticus saponaceus (Bloch & Schneider)
19/25
- *Petrolisthes galathinus* (11) 53.0%
- *Pilumnus* sp. [nr. *P. sayi*] (7) 36.8
- *Lysmata wurdemanni* (2) 10.5
- *Pilumnus pannosus* (2) 10.5
- *Pseudomedaeus agassizi* (1) 5.3
- *Synalpheus fritzmuelleri* (1) 5.3
- Amphipoda (1) 5.3

Serranus subligarius (Cope)
22/26
- Amphipoda (14) 27.3%
- *Caprella penantis* (26) 13.6
- *Pilummus* sp. [nr. *P. sayi*] (3) 13.6
- Isopoda (3) 9.1
- *Hexapanopeus paulensis* (2) 9.1
- *Petrolisthes galathinus* (2) 9.1
- *Pilumnus pannosus* (2) 9.1
- *Synalpheus fritzmuelleri* (2) 9.1
- Xanthidae (2) 9.1
- *Dromidia antillensis* (1) 4.5
- *Elasmopus rapax* (6) 4.5
- *Lysmata wurdemanni* (2) 4.5
- *Leptochela serratorbita* (2) 4.5
- *Lucifer faxoni* (1) 4.5

NEKTONIC FISH

Occasional Nektonic Fish

Caranx latus Agassiz
1/7
- None

Rachycentron canadum (Linnaeus)
2/2
- *Arenaeus cribrarius* (1) 50.0%
- *Callinectes similis* (9) 50.0
- *Panaeus aztecus aztecus* (1) 50.0
- *Portunus gibbesii* (1) 50.0
- *Sicyonia brevirostris* (1) 50.0
- *Sicyonia dorsalis* (2) 50.0
- *Squilla empusa* (2) 50.0
- *Squilla neglecta* (1) 50.0

Resident Nektonic Fish

Archosargus probatocephalus (Walbaum)
1/1
- *Heterocrypta granulata* (1) 100.0%
- *Paguristes hewatti* (1) 100.0
- *Persephona mediterranea* (1) 100.0

Balistes capriscus Gmelin
9/10
- *Callinectes similis* (3) 33.3%
- *Hepatus epheliticus* (8) 33.3
- *Libinia sp.* (2) 11.1

Chaetodipterus faber (Broussonet)
11/20
- *Acetes americanus* (2) 18.2%
- *Penaeus aztecus aztecus* (2) 18.2
- Stomatopoda (1) 9.0
- *Trachypenaeus* sp. (1) 9.0

Haemulon aurolineatum Cuvier
4/10
- *Hepatus epheliticus* (1) 25.0%

Lutjanus campechanus (Poey)
292/389
- *Callinectes similis* 12.0%
- *Albunea paretii* 7.0
- *Squilla empusa* 6.0
- *Ovalipes floridanus* 3.0
- *Actes americanus* 3.0
- *Squilla neglecta* 3.0
- *Dardanus fucosus* 2.0
- *Trachypenaeus* sp. 2.0
- Stomatopoda 2.0
- *Caprella penantis* 1.0
- *Callinectes sapidus* <0.5
- *Hepatus pudibundus* <0.5
- *Hepatus* sp. <0.5
- *Pseudomedaeus azassizi* <0.5
- *Leptochela serratorbita* <0.5
- *Lysiosquilla scabricauda* <0.5
- *Ogyrides limicola* <0.5
- *Pagurus impressus* <0.5
- *Parthenope serrata* <0.5
- *Persephona mediterranea* <0.5
- *Petrochirus diogenes* <0.5
- *Pinnixa lunzi* <0.5
- *Portunus gibbesii* <0.5
- *Sicyonia dorsalis* <0.5

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PELAGIC TAR CONCENTRATIONS IN THE GULF OF MEXICO OVER THE SOUTH TEXAS CONTINENTAL SHELF

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ABSTRACT

Dry weight of tar from 189 neuston samples over the South Texas continental shelf ranged from 0 to 31.86 mg/m² during a two-year (1976–77) monthly monitoring study with an overall average of 1.66 mg/m². This average is not inconsistent with previously reported averages for the Gulf of Mexico, which are considerably lower than tar values reported for the Mediterranean and Sargasso Seas.

Inshore stations and offshore stations averaged slightly lower tar concentrations (1.24 and 1.43 mg/m²) than the intermediate positioned stations (2.30 mg/m²) on all transects.

Monthly average tar concentrations varied, but highest values occurred in the Spring (March–April, 6.7 and 5.8 mg/m²) and December (3.3 mg/m²) periods.

Two northern transects, one off the Port Aransas–Corpus Christi area and the other off the Port Lavaca–Port O'Connor area, averaged considerably higher tar values (1.47 and 2.32 mg/m²) than the two more southerly transects (0.54 and 0.27 mg/m²).

INTRODUCTION

Previous studies of floating tar report widely varying average concentrations from different parts of the world. Quantitative values for floating tar concentrations in the Gulf of Mexico are sparse, consisting primarily of the data from 104 samples analyzed from the Gulf of Mexico and Caribbean Sea by Jeffrey, Pequegnat, Kennedy, Vos, and James (1974) and 89 tar samples from the northern Gulf continental shelf collected during 1975 and 1976 (Jeffrey 1977).

Horn, Teal, and Backus (1970) were the first to report semiquantitatively on the concentrations of pelagic tar using a water displacement method. They found concentrations in the Mediterranean Sea of up to 540 mg/m² with a mean concentration of 20 mg/m². Morris (1971), using a wet weight method, reported considerably lower quantities of floating tar in the northwestern Atlantic, i.e., a range of 0.1 to 9.7 mg/m² with a mean of 2.2 mg/m². Butler, Morris and Sass (1973) made biweekly tows approximately 20 miles southeast of Bermuda in the Sargasso Sea in 1971 and 1972 and reported tar concentrations ranging from 0.1 to 40 mg/m² with a mean of 9.4 mg/m².

Contributions in Marine Science, Vol. 22, 1979.

Jeffrey *et al.* (1974), using a quantitative extraction method, reported the Gulf of Mexico and Caribbean Sea to be less polluted with pelagic tars (1.20 and 0.773 mg/m², respectively) than the Mediterranean and Sargasso Seas, but more than the Northeast Pacific and about the same as the Gulf Stream. They suggest that some of the pelagic tar is swept into the Gulf of Mexico through the Yucatan Straits and comes primarily from shipping and tanker-cleaning operations. Bimodal gas chromatogram traces also relate many tars to crude oil sludges or tanker wastes dumped at sea (Butler *et al.*, 1973; Sherman *et al.*, 1974; Jeffrey *et al.*, 1974).

Jeffrey (1977) reported on 89 tar samples collected by the U.S. Coast Guard during 1975 and 1976 from the northern Gulf of Mexico continental shelf and summarized tar data from Texas A&M University (TAMU) collections made between 1972 and 1975. The highest concentrations of tar were found in the South Texas continental shelf area (3.09 mg tar/m² from 18 Coast Guard samples; 1.92 mg/m² from 37 TAMU samples) and the lowest on the West Florida shelf (0.14 mg/m² from 24 Coast Guard samples; 0.43 from 9 TAMU samples). Analysis of the TAMU samples showed that tars in the western and southwestern Gulf were higher in sulfur than those in the eastern Gulf, and particularly higher than those from the west coast of Florida (Jeffrey 1977).

The present study reports upon dry weight of floating tar from 189 neuston samples collected in the Gulf of Mexico over the South Texas continental shelf from 12 station locations sampled monthly during the two-year period from February 1976 through December 1977.

MATERIALS AND METHODS

Study Area

The sampling area of the northern Gulf of Mexico off South Texas included four transects perpendicular to the shore consisting of three stations each: a nearshore station (Station 1), an intermediate station (Station 2), and an offshore station (Station 3) making a total of 12 stations (Figure 1). Stations 1, 2, and 3 at all four transects were sampled during three seasonal sampling periods: Winter (Jan.–Feb.), Spring (May–June), and Fall (September–October) producing day and night samples at each station in 1976, making a total of 72 seasonal samples. In 1977 the night samples were eliminated on all transects except Transect II, thus making a total of only 45 seasonal samples in 1977. In addition, Transect II, the transect located offshore from the Port Aransas–Corpus Christi area, was sampled during six monthly sampling periods in March, April, July, August, November and December providing day and night samples at each of the three stations, making a total of 36 monthly samples for each year in 1976 and 1977. Thus, the neuston samples analyzed for 1976 totaled 108 and for 1977 totaled 81 (Table 1).

Field Methods

A neuston net frame having an inside opening of 1 × 2 m was constructed out of solid aluminum rod. A net with a mesh size of 500 microns was lashed to the frame, and the entire net system was made to fish to an average depth of 15 cm by the addition of a styrene pontoon affixed to each of the short sides of the frame. A flowmeter was suspended beneath the frame by two stainless steel rods which allowed quantitative measurements of volume filtered as well as of surface area sampled.

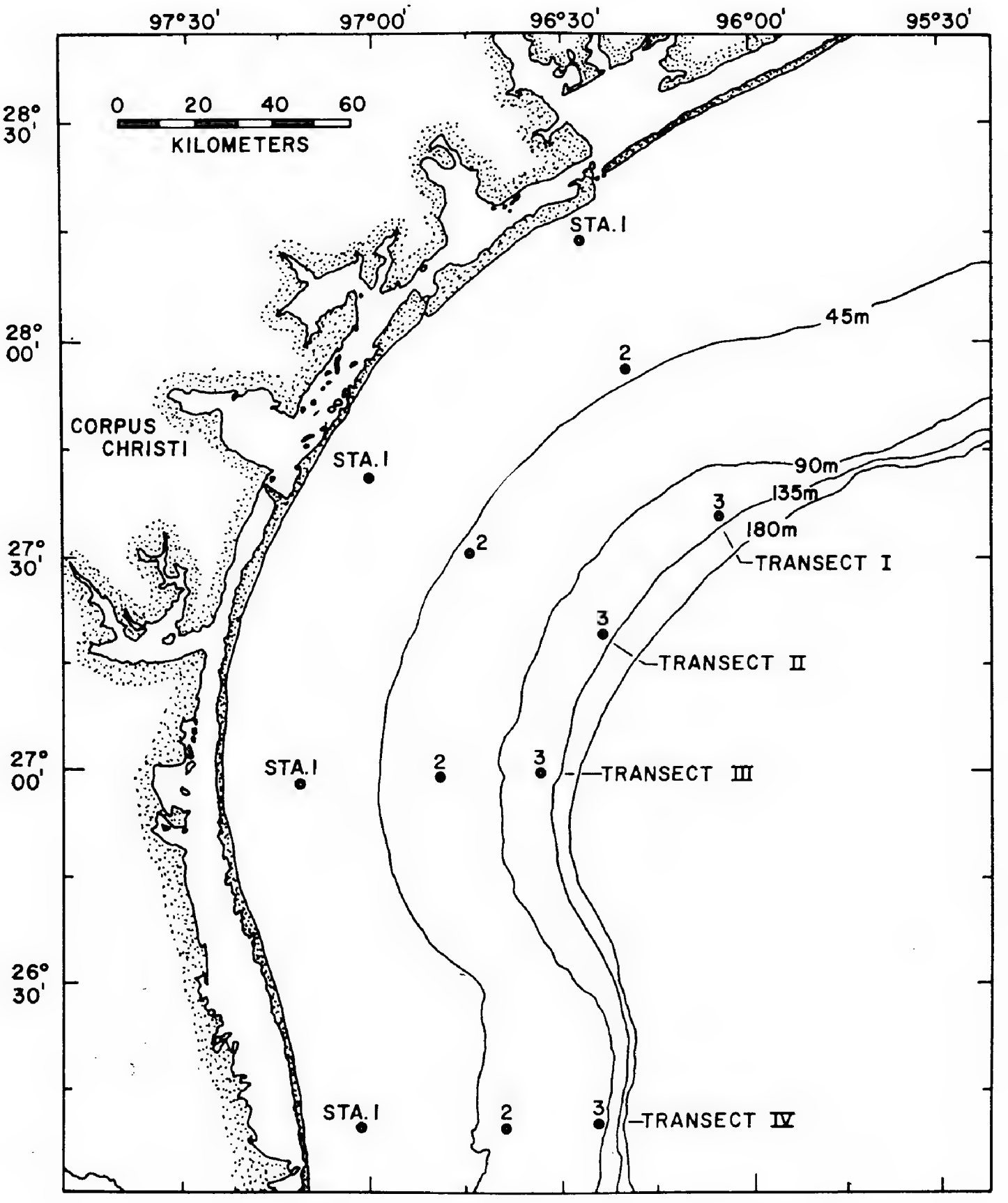

FIG. 1. Location of sampling stations for South Texas neuston samples.

It was determined that 700 rpm on the R/V LONGHORN engine produced a speed of approximately 2.4 knots in the water. All neuston tows were taken with the engine at approximately 600 rpm. The net fished about 2–5 m away from the side of the ship. At the end of a tow, retrieval was begun so that the net left the water after approximately 15 minutes of fishing. Immediately after the net was brought on deck the flowmeter was read, the net was thoroughly rinsed with the deck hose, and the contents of the cod end were transferred to an appropriate jar and preserved in a buffered 10% Formalin solution.

Laboratory Methods

Each sample was initially poured into a large pan, and all of the organisms or objects approximately 1.5 cm in size or larger were picked out. The tar particles in this "large fraction" were dried in a drying oven at 60°C for one hour and weighed. The remainder of the sample was then split in a Folsom Plankton Splitter, with one-half (chosen at random) saved for archiving. The remaining one-half was then split as many times as necessary to produce a fraction containing approximately 3,000 organisms. Any tar in this aliquot was also dried and weighed. Reports on the taxonomic analysis of the neuston organisms have also been prepared (Pequegnat, Wormuth, and McEachran 1977; and Wormuth, Pequegnat and McEachran 1979).

RESULTS AND DISCUSSION

Day-night average dry weights of tar collected during 1976 and 1977 along Transect II are plotted against time in Figure 2. The 1976 results show a relatively erratic pattern of tar concentrations, with peaks of 31.9 mg/m² at Station 2 in April and 17.76 mg/m² at the offshore station in December. The 1977

TABLE 1.

Number and arrangement of neuston samples taken at each station and transect during 1976 and 1977.

1976

TRANSECT	STATION			TOTALS
	1	2	3	
I	6	6	6	18
II	18	18	18	54
III	6	6	6	18
IV	6	6	6	18
TOTALS	36	36	36	108

1977

TRANSECT	STATION			TOTALS
	1	2	3	
I	3	3	3	9
II	18	18	18	54
III	3	3	3	9
IV	3	3	3	9
TOTALS	27	27	27	81

Transect II data show peaks in March of 20.6 and 8.5 mg/m² at stations 1 and 2, respectively.

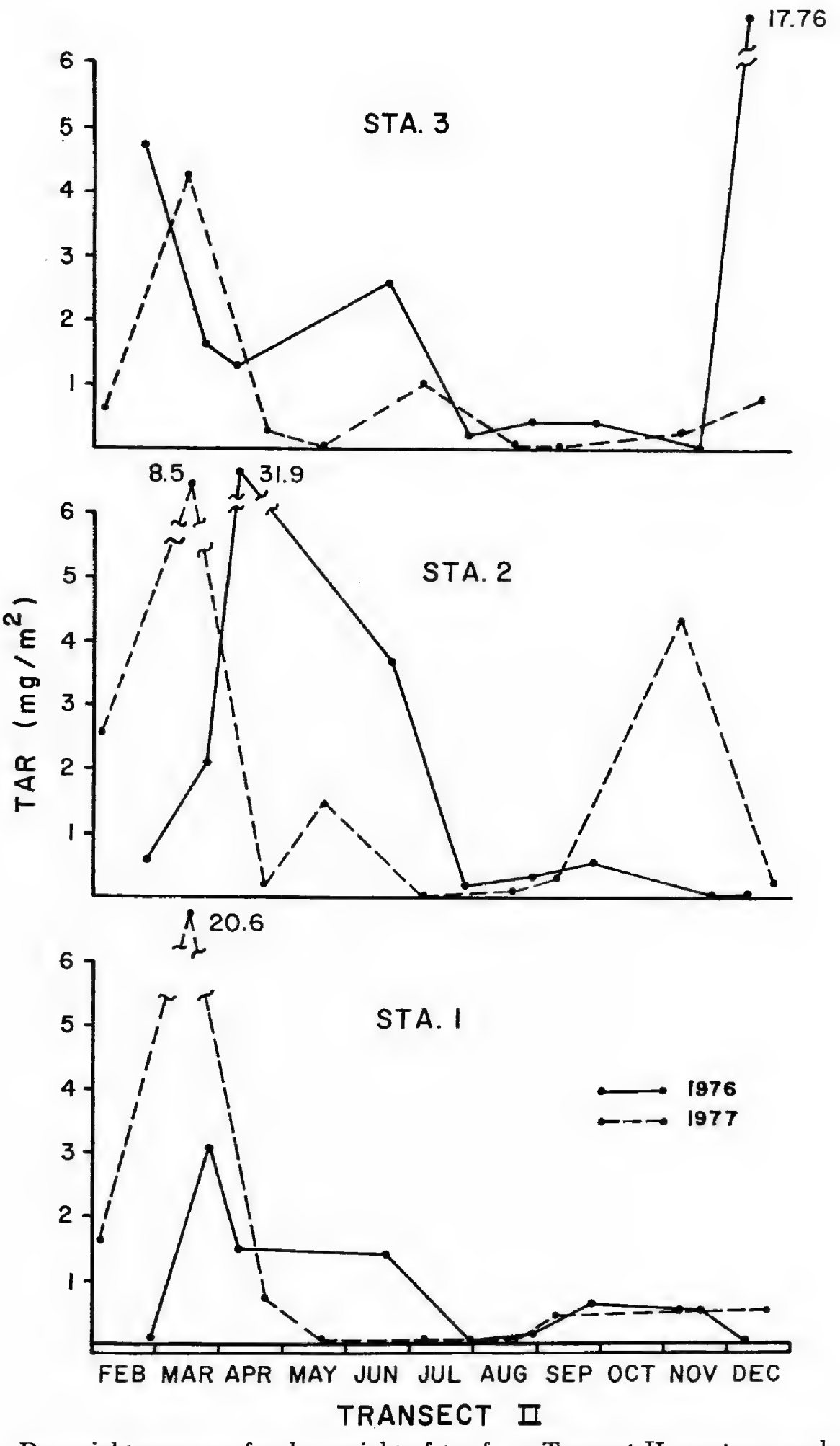

FIG. 2. Day–night averages for dry weight of tar from Transect II neuston samples during 1976 and 1977.

Tar concentrations for the 1976 seasonal samplings (as day-night averages at all four transects), shown in Figure 3, range from 0.0 to 4.7 mg/m² with no outstanding peaks in concentration such as those shown along Transect II in April and December.

Tar concentrations for the 1977 seasonal samples, plotted alongside the 1976 data (Figure 3, hashed bars), show values on Transect I exceeding those for 1976 in most cases. The 1977 data show peaks on Transect I of 9.12 mg/m² in Spring (May) at Station 2 and 5.75 and 5.42 mg/m² in Fall (September) at Stations 1 and 2, respectively. The seasonal samplings at all other transects in 1977 were generally lower in tar values than at Transect I. Transect I is located off the Port Lavaca-Port O'Connor area.

In order to determine any seasonal, nearshore-offshore, or geographical differences in tar distribution, Table 2 was prepared to show average amounts of tar by time of year, station, and transect. Several observations emerge, i.e., the relatively higher tar levels at the two northern transects compared to the two southern transects. Transect II (off the Port Aransas-Corpus Christi area) shows a two-year average of 2.32 mg/m² while Transect I (off the Port Lavaca-Port O'Connor area) showed a 2-year average of 1.47 mg/m². It is interesting to note that the 1977 average tar concentration at Transect I was over five times the value for 1976.

No consistent trends are shown in nearshore-offshore differences in tar values, except that the intermediate stations showed high values in both 1976 and 1977 (2.53 and 2.00 mg/m², respectively). The nearshore stations and offshore stations fluctuated greatly between the two years, but over the two-year period averaged less tar than the intermediate stations.

The months with the highest average tar concentrations were April and December in 1976, reflecting the major peaks in those months at Transect II, and March and November 1977, also accounted for by high values at Transect II (See Figure 2).

The two-year average of tar concentrations from all stations sampled in 1976 and 1977 on the South Texas continental shelf was 1.66 mg/m². This figure is slightly higher than the 1.20 mg/m² reported by Jeffrey *et al.* (1974) for the entire Gulf of Mexico and the 1.35 mg/m² four-year average tar concentration for 181 Gulf of Mexico stations reported by Jeffrey (1977). However, measurements based on a chemical extraction method, such as that used by Jeffrey *et al.* (1974) tend to be somewhat lower than other methods using wet or dry weights since debris accounts for between 5–77% (36.6% average) of the tar lump's mass. Therefore, the concentrations obtained from the present study by dry-weight methods are not in conflict with previous observations by Jeffrey *et al.* (1974) of lower average tar concentrations in the Gulf of Mexico than in the Mediterranean or Sargasso Seas.

No definitive explanation is offered at this time for the relatively higher tar concentrations along the Port Aransas-Corpus Christi transect and the Port Lavaca-Port O'Connor transect compared to the two southern transects except that the former are areas of heavier ship activity than the southern areas if,

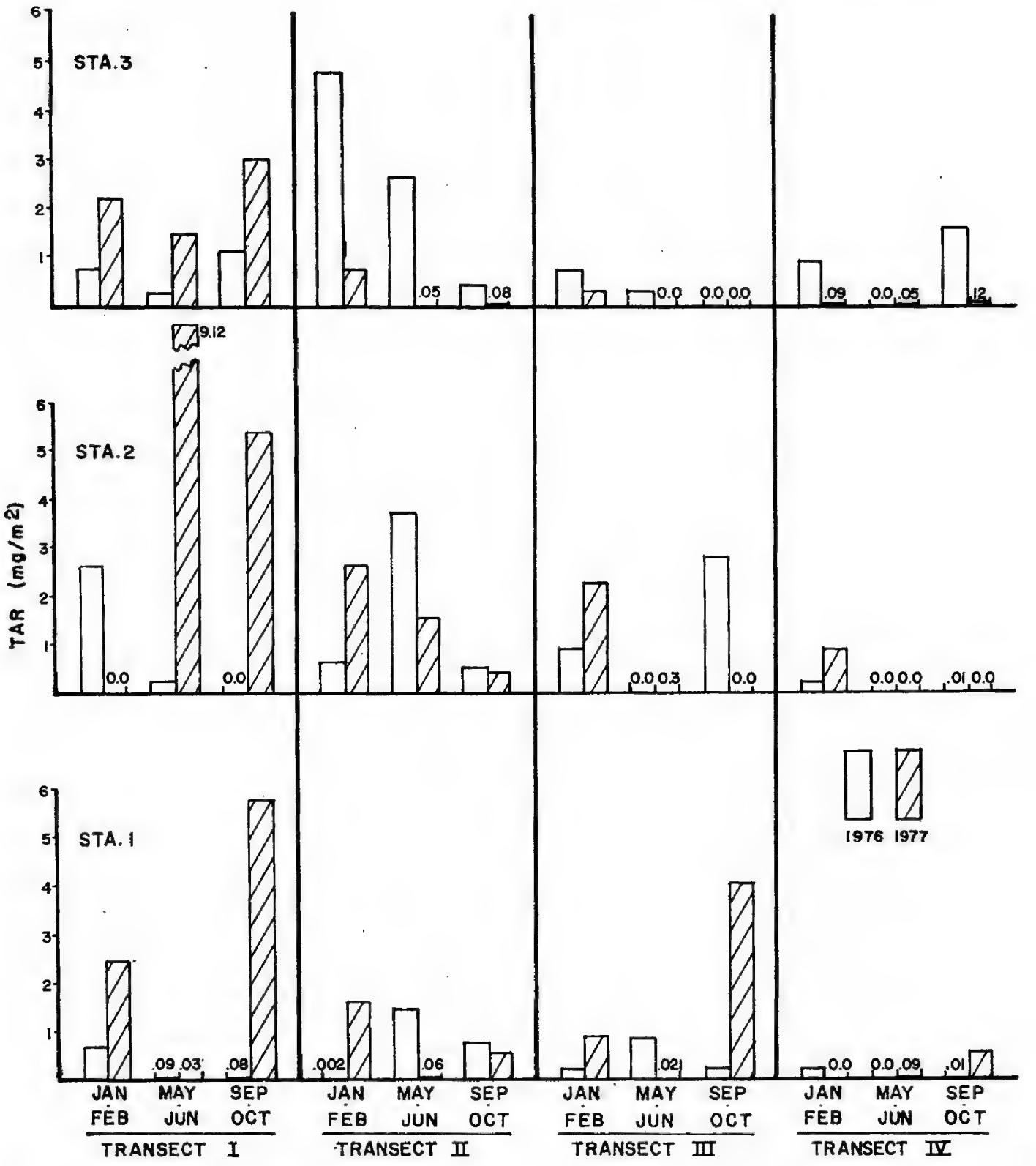

FIG. 3 Day-night averages for dry weight of tar from Transects I, II, III, and IV sampled seasonally during 1976 and 1977.

indeed, the tar is primarily from man-made sources. Jeffrey *et al.* (1974) found that 32% of the pelagic tars they examined from the Gulf of Mexico and Caribbean Sea show gas chromatograms with a bimodal distribution of peaks which represent tanker sludge residues. They further found, on the basis of high sulfur content, that at least 60% of the pelagic tars examined from Gulf and Caribbean did not originate from U.S. Northern Gulf Coast oils but from foreign crudes from the Caribbean or Middle East.

Jeffrey (1977), in order to explain the relatively higher tar concentrations she found for the South Texas continental shelf area (3.09 and 1.92 mg/m^2 from

18 Coast Guard and 37 TAMU samples, respectively, compared to the 1.23 and 1.35 mg/m² average values for the entire Gulf of Mexico), theorizes that there is (1) either a large source of tar in the southwestern Gulf that is swept northward off the South Texas coastline and/or (2) the surface currents in the Gulf concentrate the floating tars on the western boundary of the Gulf. Data from the present study indicate that pelagic tars are not concentrating in the southern end of the South Texas continental shelf area; i.e., south of Corpus Christi. In fact, pelagic tar concentrations from this southern area are considerably below the average tar values for the entire Gulf (0.41 mg/m² compared to Jeffrey' (1977) entire Gulf value of 1.35 mg/m²).

TABLE 2

Average dry weights of floating tar by season, station, and transect off South Texas in 1976 and 1977.

MONTH	NO. OF SAMPLES AVERAGED (1976)	(1977)	TAR (mg/m²) 1976	1977	2-Year Average
WINTER (Jan-Feb)	24	15	0.99	1.26	1.09
MARCH	6	6	2.25	11.11	6.68
APRIL	6	6	11.21	0.41	5.81
SPRING (May-June)	24	15	0.78	0.93	0.84
JULY	6	6	0.12	0.46	0.29
AUGUST	6	6	0.27	0.08	0.18
FALL (Sept.-Oct.)	24	15	0.62	1.38	0.91
NOVEMBER	6	6	0.18	1.76	0.97
DECEMBER	6	6	5.92	0.57	3.25
STATION					
1 (nearshore)	36	27	0.52	2.20	1.24
2 (intermediate)	36	27	2.53	2.00	2.30
3 (offshore)	36	27	1.86	0.84	1.43
TRANSECT					
I	18	9	0.58	3.27	1.47
II	54	54	2.76	1.88	2.32
III	18	9	0.65	0.42	0.58
IV	18	9	0.32	0.21	0.28
OVERALL AVERAGE:	108	81	1.64	1.68	1.66

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SEASONAL DYNAMICS OF SALT MARSH PLANT ASSOCIATIONS IN LOUISIANA

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ABSTRACT

Vegetation associations in southeastern Louisiana salt marshes were determined using two sampling methods. Six associations were found: three were monospecific and three were multispecied. In the monospecific associations, species phenology was the factor controlling seasonal dynamics. In multispecied associations phenology played a similar role but the resulting dynamics were more complex due to the larger number of species present. Physical gradients in the marsh were examined in relation to the sequence of these vegetation associations from open water inland. In addition, applicability of the two methods to marsh vegetation is discussed and problems presented.

INTRODUCTION

In recent years much interest and concern for salt marsh ecosystems has developed. Realization of their importance in the health, productivity and continued existence of large areas of coastal lands (Gosselink, Odum and Pope 1974) have promoted many studies concerned with various aspects of these systems. Considerable information has been gathered on the plants of the marshes (Thorne 1954, Chapman 1960, Chabreck 1972, Eleuterius 1973), their zonation (Jackson 1952, Hinde 1954, Adams 1963, Flowers 1973) and their rates of production (Keefe 1972; Odum and Fanning 1973; Gabriel and de la Cruz 1974; Turner 1976; White, Weiss, Trapani and Thien 1978). The bulk of these works has taken place in Atlantic Coast marshes.

Louisiana contains 53% of the approximately 3,174,333 hectares of salt marsh along the Atlantic and Gulf Coasts of the United States (Eleuterius 1976). These marshes are derived from previous activity of the Mississippi River and the resulting numerous abandoned deltas. Variations exist in these marshes due to the differing range of compaction, subsidence and wave modifications. The soils resulting from these processes are today classified into peats, mucks and clays with numerous intergradations possible (Brupbacher, Sedberry and Willis 1973).

Tidal activity in Louisiana marshes is moderate with an amplitude of 6.5 dm. and a cycle of approximately 24 hours; spring tides occur monthly (Marmer 1954). Normal high tides usually inundate much of the marsh. But, the winds determine the level from which the tides originate and the depth to which the

marsh is flooded. This is important due to the seasonal nature of the winds, northerly in winter and southerly in summer.

Marsh history, tidal activity, wind patterns, inundation, soil type and salinity are elements of the environmental complex that must be dealt with by any successful marsh species. Many of these parameters are fluctuating, e.g., wind, tides, salinity; some daily, some monthly and some seasonally. The plants of the marsh have developed ranges of tolerance to these conditions. In so doing, distinctive associations have formed. The composition of these assoociations and the dynamics of individual species in Louisiana salt marshes will be described in this paper. Emphasis will be placed on the seasonality of the dynamics and probable causes. In addition, the applicability of two sampling methods will be discussed.

MATERIALS AND METHODS

The study was carried out in southeastern Louisiana along Bayou Terre aux Boeufs in St. Bernard Parish (Fig. 1). Six sites located along the bayou were selected as representative of the vegetation associations seen in the salt marsh. Each site was a minimum of 500 by 500 meters. All sites except site 3 were bound on at least one side by open water. Site 3 was fronted by a small levee and a band of annually burned *Distichlis spicata*. Tidal influences originated from the rear at this site.

Data at these sites were collected at approximately monthly intervals from March 1975 to March 1976. The vegetation was sampled using both the quadrat method and the line intercept

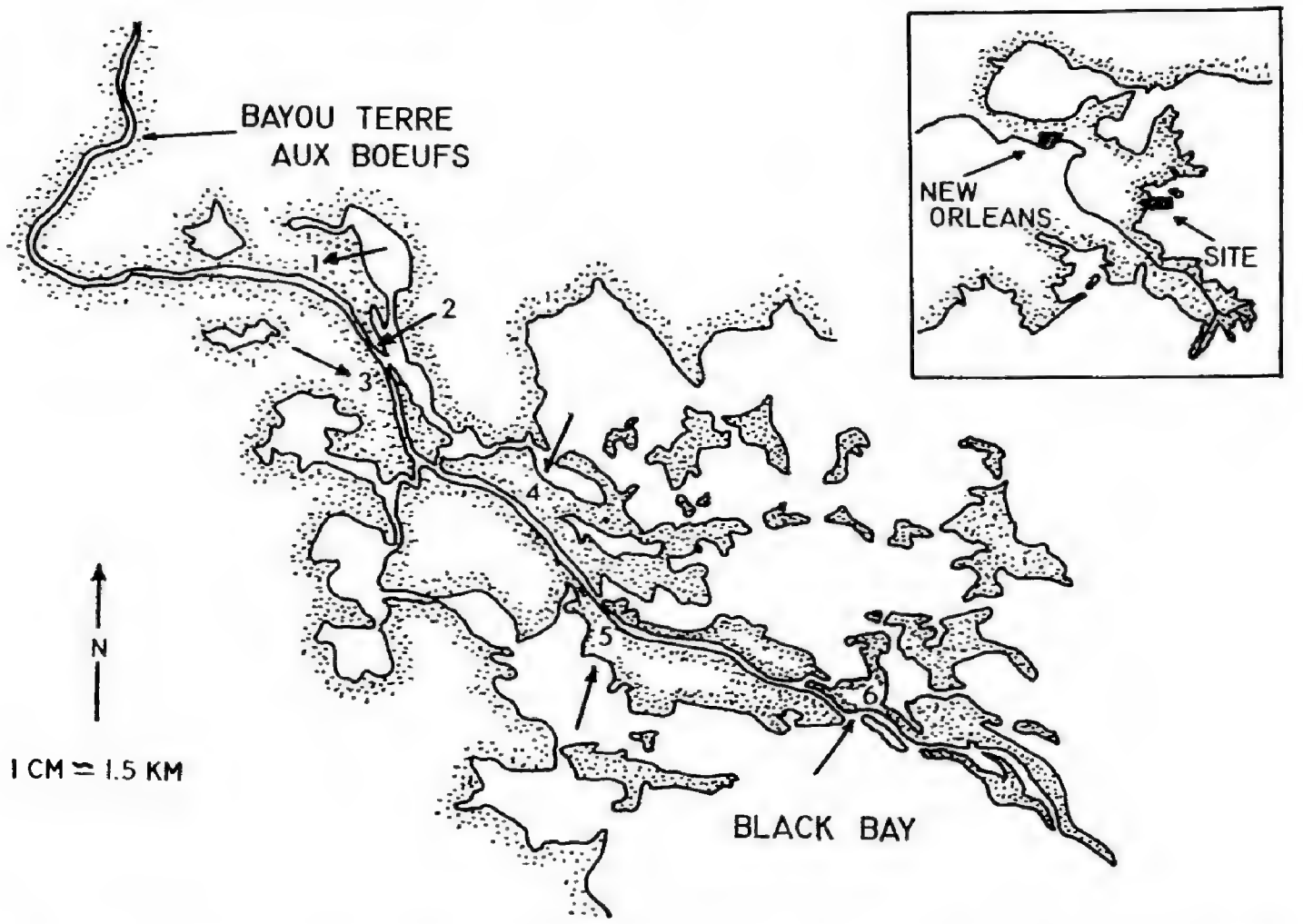

FIG. 1. Location of the study area indicating sample sites along Bayou Terre aux Boeufs. See text for site descriptions.

method (Cox 1976). This was done to provide a more complete picture of the vegetation at each site.

At each site a random point along the shoreline or site front was selected on each sampling date. Proceeding from this point, ignoring any shoreline vegetation, a transect was visually run across the site perpendicular to the shoreline. The vegetation along this transect was sampled by an alternation of quadrats and line intercepts, 1 to 4 respectively. At some sites only quadrats were used.

All vegetation within 3 to 6 quarter square meter quadrats was clipped just above soil level. These clippings were returned to the lab for sorting into species and separation into live and dead components. Relative frequency, relative density, relative dominance and importance values were calculated (Cox 1976).

In the line intercept method a modification of the procedure introduced by Canfield (1941) was developed. A four-meter wooden pole marked in one meter intervals was pushed along the marsh surface parallel to the transect. The number of live stems of each species in contact with the pole was recorded. Twelve to twenty-five such intercepts were combined with a diameter measurement to calculate the same indices generated in the quadrat method.

Surface and interstital water salinities were measured in situ on each sampling date, when possible, with a Model 33 YSI salinity-conductivity-temperature meter (Yellow Springs instrument Co., Yellow Springs, Ohio).

Botanical nomenclature follows Correll and Correll (1975) and Radford, Ahles and Bell (1968).

RESULTS

The six sites vary greatly in their species composition, but there is also much overlap between sites. Sites 1, 3 and 6 show the fewest numbers of species and do visually appear as uniform stands of *Spartina cynosuriodes*, *S. patens* and *S. alterniflora*, respectively. However, at each of the sites, additional species can be found but only as rare individuals. *Borrichia frutescens* is present at site 1; *D. spicata* and *Scirpus robustus* are found at site 3; while site 6 has *D. spicata* and a few scattered seedlings of *Avicennia nitida*. These sites can thus be considered monospecific since the dominant species comprises greater than 95% of all stems present. The density of the dominant *Spartina* in each site is presented in Figure 2. It shows that the *Spartina* present at each site exhibits a period of maximum culm numbers, this being a seasonal phenomenon related to species phenology.

The remaining sites 2, 4 and 5 are multispecied. Only five species are present in amounts sufficient to warrant study of their dynamics. Three of these are the species of *Spartina* mentioned above. *S. cynosuroides* is found at site 2 and *S. alterniflora* at sites 4 and 5, whereas *S. patens* is present at all three sites. Six other plants are common to all three sites. Four of these, *Aster tenuifolius*, *B. frutescens*, *Eleocharis* spp., and *Salicornia virginica*, are infrequent in abundance while *D. spicata* and *J. roemerianus*, the remaining two, are present in significant amounts. It is these latter two species plus the three spartinas that were studied in detail. The remaining plants mentioned below are found infrequently at the sites. *Agalinis maritima* and *S. robustus* are common to sites 2 and 4. Several species are found at only one site: *Baccharis halimifolia* and *Fimbristylis castanea*, site 1; *Lythrum lineare*, site 4, *Batis maritima*, site 5.

Site 5 is multispecied but only two species are present in large numbers, *S. alterniflora* and *J. roemerianus*. Figure 3 illustrates the patterns shown by these

two species and the sparseness of other species. *J. roemerianus* shows a peak in importance in November. Discrepancies between the methods can be seen when comparing A and B in Figure 3.

Site 4, Figure 4, and site 2, Figure 5, are both composed of numerous species. Site 2 shows a similarity to site 5 in that an early dominant *D. spicata* declines in importance as *S. patens* increases in importance towards the end of the year.

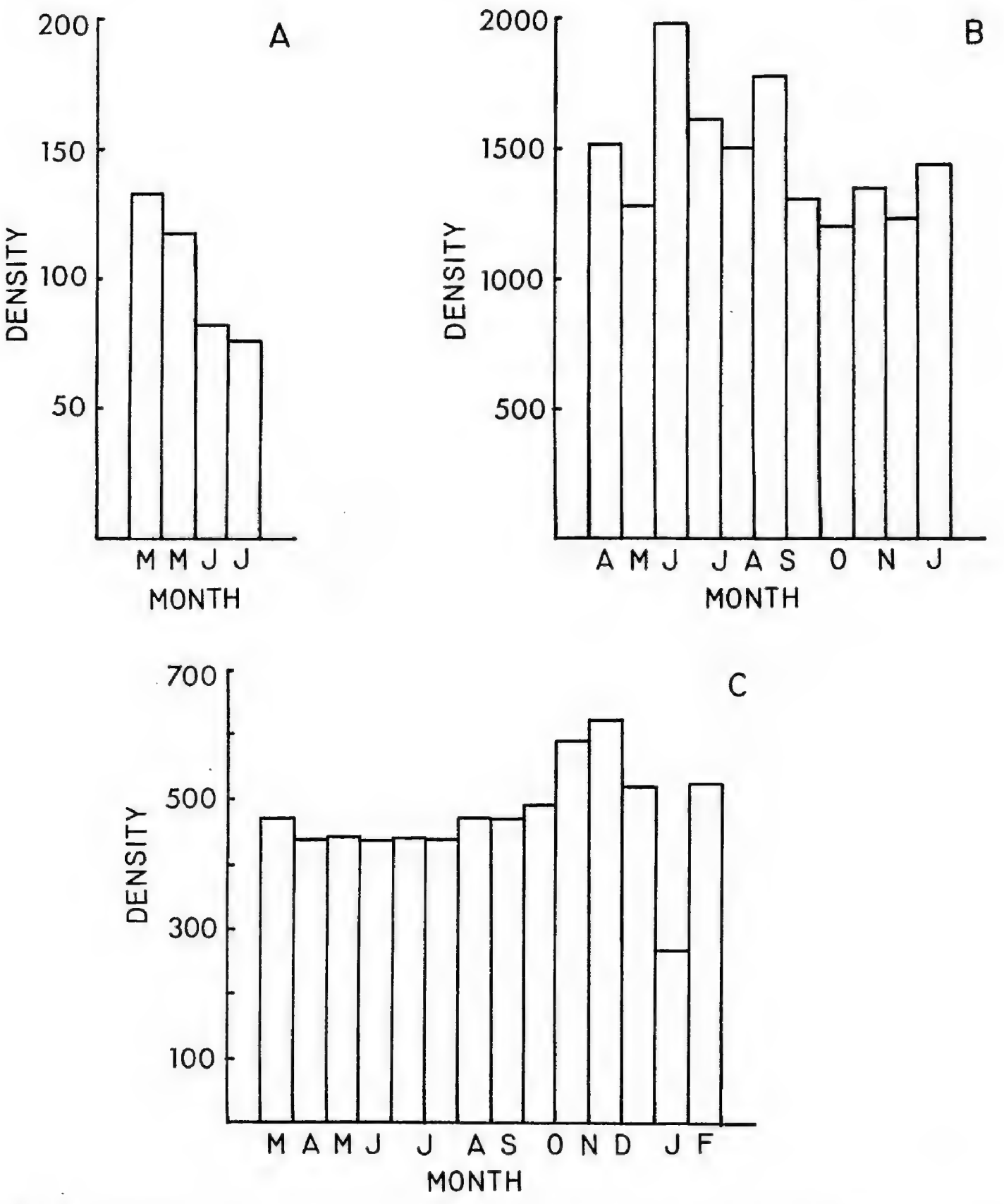

FIG. 2. Densities in live culms/m² at particular months of the year for the three monospecific sites. A) site 1—*Spartina cynosuroides*; B) site 3—*Spartina patens*; C) site 6—*Spartina alterniflora*.

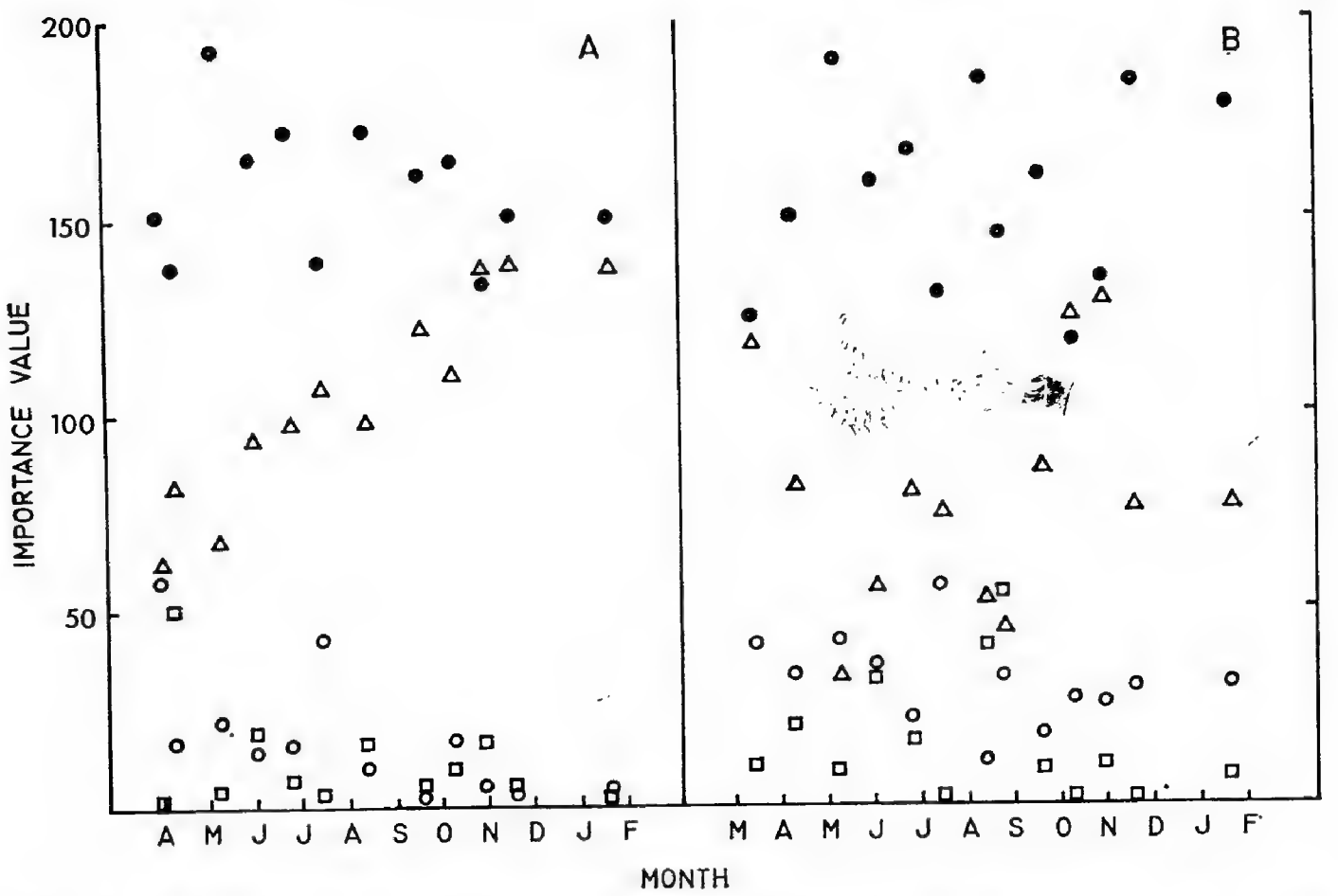

FIG. 3. Species importance values at site 5 from (A) line intercept method; (B) quadrat method: ● *Juncus roemerianus*, ○ *Distichlis spicata*, △ *Spartina alterniflora*, □ *Sparatina patens*.

The most conspicuous species at this site *S. cynosuroides* maintains a very stable but reduced position throughout the year.

Site 4, Figure 4, presents a more complex picture than either other multispecied site. *D. spicata* is again the dominant species but here shares overall importance with *S. alterniflora* and *S. patens*. These two spartinas increase in importance in the Fall following the spring-early summer peak in importance for *D. spicata*. Further discrepancies in species seasonal trends are evident between the two methods, especially for *S. patens*.

Salinities from five sites (site 1 omitted) are presented in Table 1. From the limited data available, there is some indication that summer is the period of highest salinity, both in surface and interstitial waters. More evident, however, is the variation within sites and overlap between sites.

DISCUSSION

The quadrat and line intercept methods accurately sample species associations in the salt marsh. At the multispecied sites the two methods provide data that is consistently similar except for two discrepancies. Since the line intercept method is a field method, there can be inaccuracies in determining the live/dead status of particular stems. In the laboratory greater care can be taken as more time is available. This appears to be the problem at site 5 (Fig. 3) where the post-flowering importance of *S. alterniflora* differs between the two methods. Meticulous care in the field would easily correct this inaccuracy.

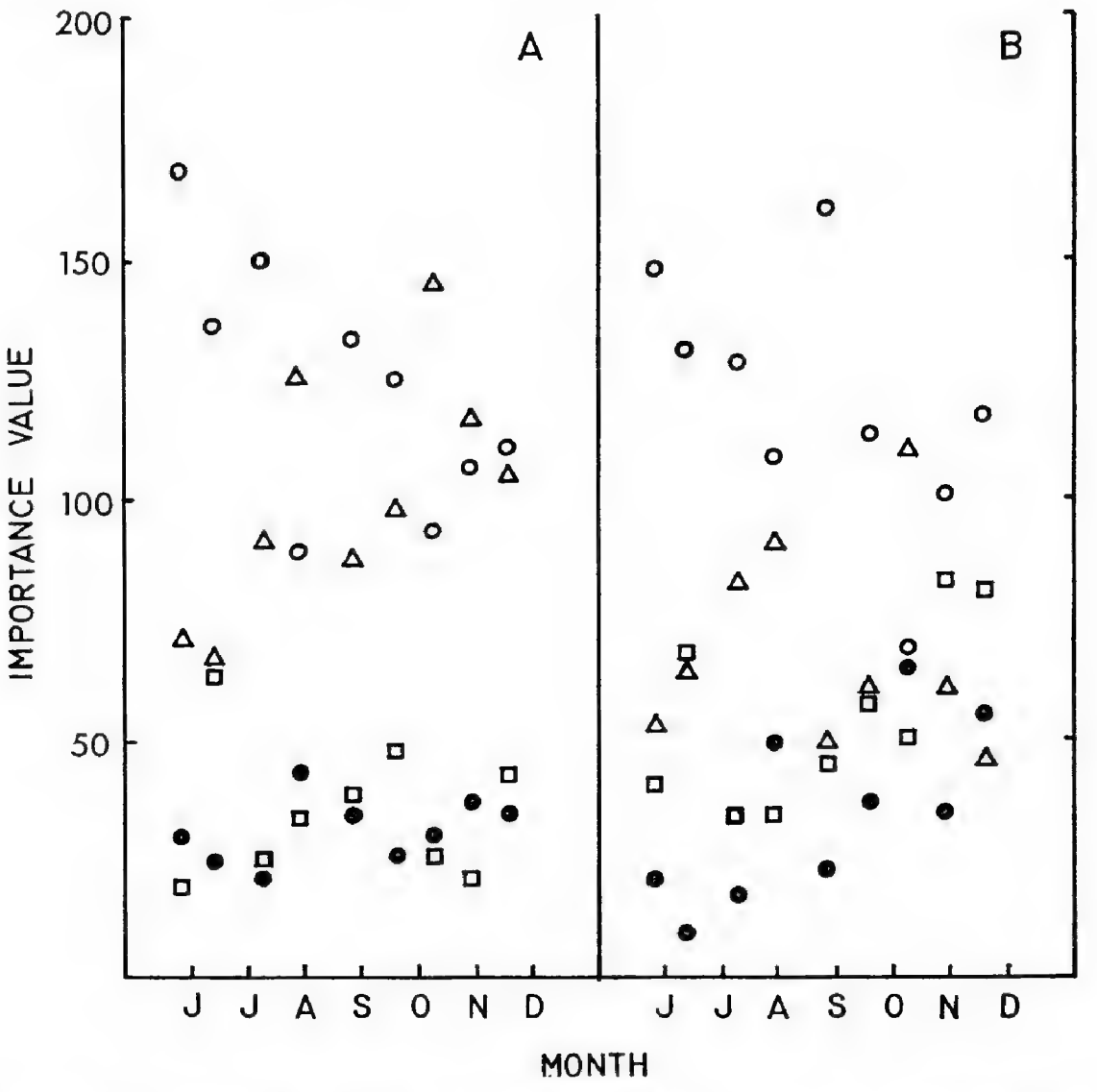

FIG. 4. Species importance values at site 4 from (A) line intercept method; (B) quadrat method: ● *Juncus roemerianus*, ○ *Distichlis spicata*, △ *Spartina alterniflora*, □ *Sparatina patens*.

An early modification to this joint method procedure was the elimination of the line intercept method at sites consisting of one species: sites 1, 3 and 6 (Fig. 2). At these sites density is the important measured value and is more accurately obtained from the quadrat method. The line intercept data is only considered on a relative basis and, thus, is not as meaningful.

A more difficult problem is the general underestimation in importance of small stemmed species which are clumped in distribution, e.g. *S. patens*. This is the reason that at site 4 (Fig. 4) the clipped method shows an increase in importance during the fall for *S. patens* while the line intercept method does not. Similarly, the larger stemmed *S. cynosuroides* at site 2 (Fig. 5) obscures the late spring decline in *S. patens* importance. No immediate solution is apparent for this problem.

When considering marsh dynamics, it is immediately obvious that change, independent of magnitude, revolves around only a few species. Three of the sites in this study, 1, 3 and 6, are essentially monospecific. Sites 2, 4 and 5 are multispecied and share numerous species but differ in the importance of these species.

Site 1, a stand of *S. cynosuroides*, is the association which marks the inland extension of the salt marsh. This association, though not extensive in area, is an

important indicator of the landward limit of the saline and tidal influences of flooding waters. Areas exemplified by site 1 are visibly higher than mean tide levels and are irregularly flooded. Salinity at this site should be lower than any other site. The decline in culm numbers from early spring into summer shows a clear seasonal trend (Fig. 2). This decline precedes the time of flowering (July–August) and is in contrast to the patterns of the other spartinas in the marsh. *S. cynosuroides* flowers earlier than the other spartinas and appears to concentrate its growth into the spring and summer. It is the largest *Spartina* in the marsh and may not be able to support all the new shoots originating each spring, thus showing mortality in culms during the time of flowering.

A second *Spartina* association, this dominated by *S. patens*, is seen at site 3. This *Spartina* shows a mid-summer decline in culm numbers (Fig. 2) which is not directly correlated with flowering. Flowering (July–September) commences in *S. patens* at this time but not in areas exemplified by site 3. These areas reproduce only vegetatively with year-round growth and new shoots appearing in late fall and early winter. Though flowering does not regularly occur in this association, the mid-summer peak in culm numbers followed by decline until new shoots appear is an outward manifestation of this phenological event. This pattern is important in multispecied sites in which *S. patens* is an influencing component. Over all, this association is an extensive component of the salt marsh (White *et al.* 1978).

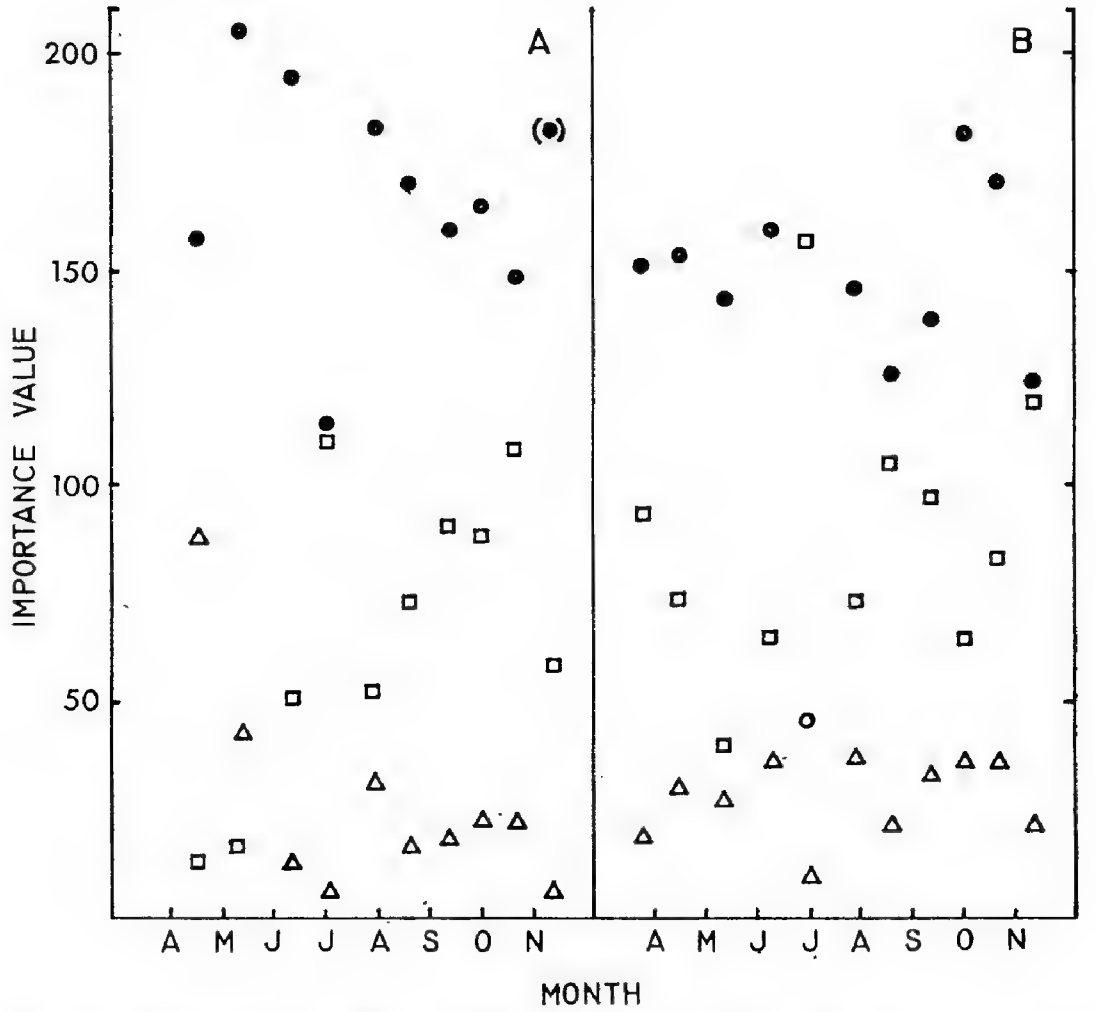

FIG. 5. Species importance values at site 2 from (A) line intercept method; (B) quadrat method: ● *Distichlis spicata*, □ *Spartina patens*, △ *Spartina cynosuroides*. (◉) The importance value for this sampling date was 230.

The last monospecific site, site 6, is dominated by *S. alterniflora.* This association clearly shows a pattern determined by flowering (Fig. 2). Fowering occurs from early to mid-fall with new shoots appearing after the first of October. Numbers of *S. alterniflora* culms remain constant from March to September and then rise significantly until old culms begin collapsing in late December. This pattern is also seen in the average height of the culms as it drops from 50 cm. in October to 25 cm. in December (Weiss, unpublished data). *S. alterniflora* also exhibits year-round growth.

The least complicated multispecied association is represented by site 5. Not only are there fewer species but only two of those present are important in the dynamics of the association (Fig. 3). *J. roemerianus* dominates this association both visually and numerically. *S. alterniflora* reaches levels of equal importance late in the year. *J. roemerianus* is the only dominant in the salt marsh that blooms in the first half of the year. From observations in this study and extensive work by Eleuterius (1975) in Mississippi marshes it is known that flowering occurs as early as January and peaks in mid-March. *J. roemerianus* stems are longer-lived than stems of other salt marsh dominants, usually flowering after 18–24 months. These two factors explain the seasonal pattern exhibited by *J. roemericanus.* As new stems appear from early winter through spring, stem numbers increase; vegetative and reproductive stems begin dying shortly thereafter. In this association the importance of *J. roemerianus* shows such seasonal trends.

S. alterniflora in site 5 deviates slightly from the pattern seen in site 6. Here there is a steady increase in importance from spring to winter (method differences aside) followed by a decline after flowering. Just prior to this decline in importance, *S. alterniflora* and *J. roemerianus* co-dominate the association. Seasonally, this association fluctuates from *J. roemerianus* dominance from mid-winter through summer to *J. roemerianus–S. alterniflora* codominance in the fall and early winter.

The two remaining associations, sites 2 and 4, show numerous similarities in both composition and species importance. *D. spicata* dominates both associations (Fig. 4 and 5) but coexists with different species at the two sites. In the inland progression of salt marsh associations, *S. alterniflora* decreases in importance and is replaced by *S. patens.* Site 4 (Fig. 4) illustrates the shared subdominance of these two species and site 2 (Fig. 5) shows the next step in which *S. patens* is solely subdominant and *S. alterniflora* is a minor constituent. *J. roemerianus* shows similar trends to *S. alterniflora,* less important at site 4 and uncommon at site 2. *S. cynosuroides* makes its first appearance as a constituent of these associations at site 2.

D. spicata in both associations shows a peak in importance during the spring (Figs. 4 and 5) with a decline through summer and fall. The reason for this is that *D. spicata* does not show the overlap in new growth that the spartinas do. The culms are initiated in late winter or early spring and are dead by winter. Flowering occurs during the summer (July–August) and again marks the point from which the species declines in importance.

Site 4 (Fig. 4) again shows the late fall peak in importance of *S. alterniflora*

TABLE 1

Monthly surface and interstitial water salinities for sites 2 through 5.
Salinity in parts/thousand.

Site	2		3		4		5		6	
Water type	S[1]	I[2]	S	I	S	I	S	I	S	I
March	--	--	--	--	--	--	--	--	8.0	--
April	--	9.0	6.0	8.5	--	--	--	10.0 8.5[3]	6.0	--
May	3.5	--	5.0	9.0	--	--	--	19.0	5.0	--
June	2.0	--	--	8.5	3.8	7.0	5.0	--	3.0	--
July	--	--	5.0	--	--	14.0 19.0[3]	7.3	23.5	15.0 17.0[3,4]	
August	7.0	--	5.5 5.0[3]	--	8.8	--	5.5	--	7.5	--
September	5.0	7.5	4.0	--	5.0	--	--	--	6.5	--
October	4.0	--	5.0	--	5.5 3,5[3]	--	5.0	6.5	--	9.0 7.5[3]
November	4.0 0.1[3]	--	--	--	3.0	--	3.5	--	--	--

1—denotes surface water, above marsh surface
2—denotes interstitial water
3—more than one measurement from that month, upper one is earlier
4—both surface and interstitial water mixed

and the post-flowering decline. *S. patens* shows late fall increases in importance that are probably maintained until early spring when *D. spicata* becomes active. This association, then, shows three periods with different profiles: spring and summer dominated by *D. spicata*, fall codominated by *D. spicata* and *S. alterniflora* and winter codominated by *D. spicata* and *S. patens*.

Site 2 (Fig. 5) shows two of the profiles seen in site 4 but here *S. patens* completely replaces *S. alterniflora*. *D. spicata* dominates during spring and summer and *D. spicata* and *S. patens* codominate this association during fall and winter.

In all of these associations, it is clear that the seasonal fluctuations of individual species, primarily the dominants, establish patterns for the entire association. Phenology plays a primary role in this seasonality with flowering being the most important single factor. Further evidence of this correlation is evident in the biomass-production studies on these salt marsh dominants (White *et al* 1978).

These six associations also illustrate the sequence in vegetation seen proceeding from the open water limit to the inland limit of Louisiana salt marshes (Fig. 1). Many physical gradients parallel this vegetation sequence but no single

factor can adequately explain this sequence. Figure 6 characterizes this progression of previously described vegetation associations in relation to probable causative factors.

Salinity is the most obvious gradient in the salt marsh. Salinity of surface and interstitial waters does decrease from open water inland but not in definable steps. Much overlap occurs among sites (Table 1) and only broad ranges can be given for particular sites.

Salinity as a factor determining association composition appears most important in areas nearest open water, sites 4, 5 and 6 (Fig. 6). Here the effects of salinity are harshest and most limiting. In contrast, the three inland associations seen in sites 1, 2 and 3 show stronger dependence on factors other than salinity for association differentiation. This is not unexpected as it is known that salt marsh plant species exhibit broad salinity tolerances (Chabreck 1972).

Concomitant with these salinity ranges is the occurrence of some species in numerous associations. These species though showing different importances do occupy characteristic habitats in the various associations. *S. patens* occupies areas of greatest standing water in sites 3 and 2 and directly behind site 1. It is also found at site 4 but here occupies drier areas due to the higher salinity of the standing water. *D. spicata* is found in areas of little standing water in sites 2 and 4 and in an elevated band fronting site 3. These examples illustrate the limited applicability of salinity in explaining the overall vegetation sequence and stress the basic importance of salinity in determining the actual position of a species within an association (cf. *S. alterniflora* in Fig. 6).

Two other components of salinity further complicate any correlation with vegetation. First, salinity exhibits a seasonal pattern of its own. Winter is the period of lowest salinities throughout the marsh but of greatest fluctuation. Summer is a relatively stable period showing the highest salinities (Geyer 1950). Two factors contribute to this pattern: Mississippi River discharge variations and seasonal weather patterns.

Second, the soils of the marsh vary considerably in their salt exchange capacities (Brupbacher *et al.* 1973). Plants growing in peats, e.g. sites 2 and 3, have to deal with a much different soil-salt environment than do plants growing in a clay soil, e.g. site 6. Such soil differences in conjunction with the other salinity components sharply reduce the value of any vegetation-salinity correlation.

In the more inland associations (sites 1, 2 and 3), gradients of elevation and flooding, increasing and decreasing inland respectively assume greater importance (Fig. 6). These two factors are difficult to separate but are not always directly related. For example, the *S. patens* association, site 3 (Fig. 2), is high in elevation but shows long periods of standing water though considerably removed from direct tidal influences (Fig. 6). Blum (1968) considers both the presence of standing water and the extent of elevation characteristic of this association. Again, correlation of the vegetation associations found in the marsh with a single physical gradient is only partially successful.

In conclusion, physical factors are important determinants of association composition but in a complex fashion. Individual factors do not act independently

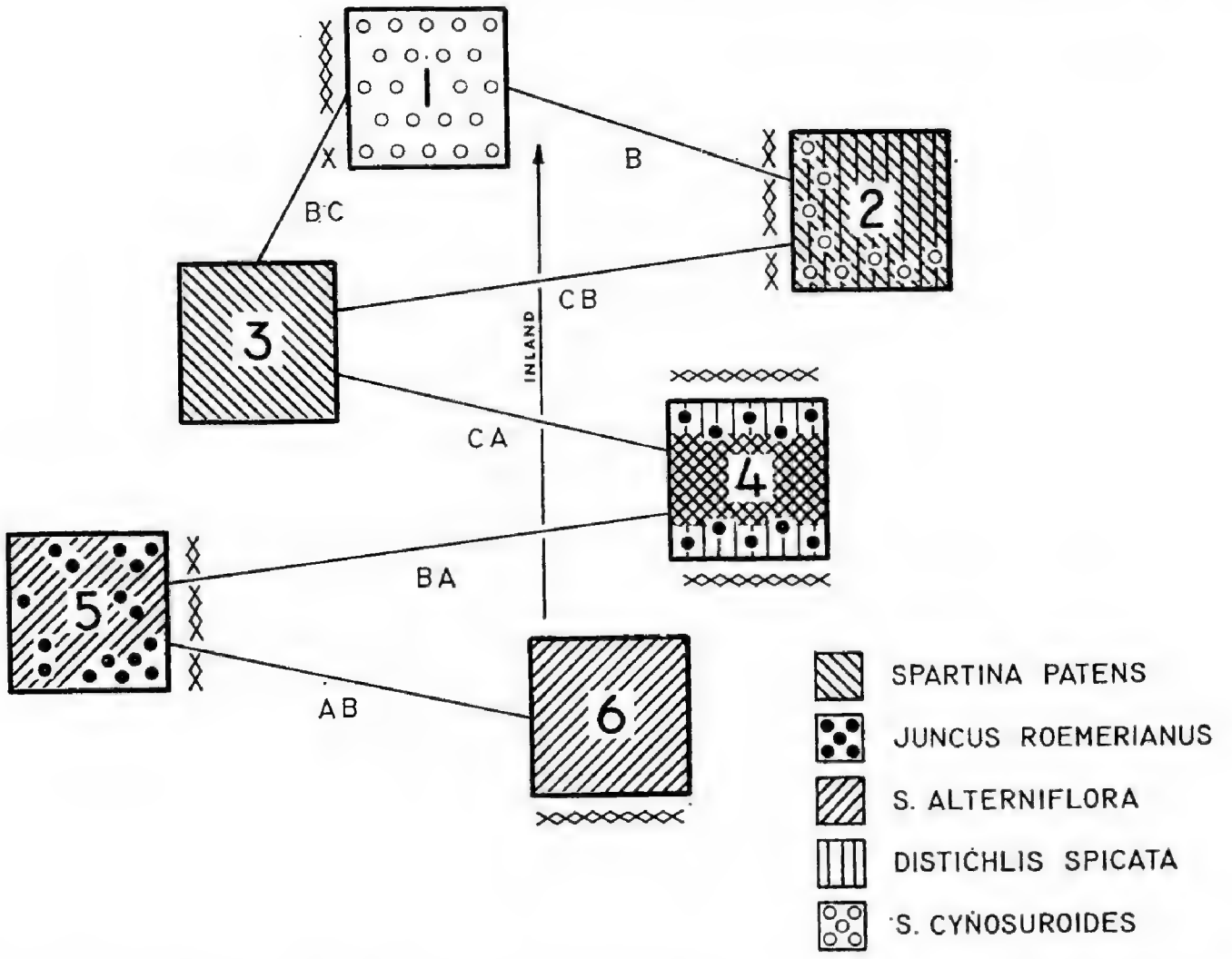

FIG. 6. Composition of the six associations in the sequence from open water (site 6) inland (site 1). Letters indicate factors important in determination of association composition (A—salinity, B—elevation, C—standing water). The primary factor is listed first, secondary factor if present follows. XX indicates shoreline.

and often show much inherent variability along the vegetation sequence, e.g. salinity. It is the interaction of these factors, standing water, salinity, soil type, elevation and flooding, that ultimately determines the vegetation present at a particular location in the marsh. The resulting vegetation associations show seasonal changes that are closely correlated with the phenology of the dominant species.

ACKNOWLEDGMENTS

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A NEW MARINE CERCARIA (DIGENEA: APOROCOTYLIDAE) FROM THE SOUTHERN QUAHOG *MERCENARIA CAMPECHIENSIS*

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ABSTRACT

A new larval aporocotylid trematode, *Cercaria mercenariae* n. sp., is described from the gonadal tissue of the Southern quahog *Mercenaria campechiensis* (Gmelin) collected from Galveston, Texas. *C. mercenariae* most nearly resembles *Cercaria loossi* Stunkard, 1929. This is the first report of a cercaria from clams of the Genus *Mercenaria*.

INTRODUCTION

Adult digenetic trematodes of the Family Aporocotylidae are parasites of the circulatory system of fishes and reptiles. The larvae of marine species develop in sporocysts in bivalved molluscs, and in either sporocysts (Linton 1915) or rediae (Martin 1952) in polychaete annelids. The cercariae are apharyngeate, longicercous, and brevifurcous. A penetration organ is present on the anterior end of the body, connected by long ducts to four or five pairs of midbody penetration glands. A median dorsal fin is often present on the body and fins may also be present on the caudal furcae.

Aporocotylid trematodes have an unusual life cycle in which there is no encysted metacercarial stage. The cercariae leave the intermediate host and penetrate directly into the circulatory system of the definitive vertebrate host.

MATERIALS AND METHODS

Southern quahogs were hand collected in the intertidal zone on the northwestern shore of Galveston Island at San Luis Pass and Terramar Beach, Texas. The animals were dissected in 20 ppt. artificial seawater and various tissues were inspected under a dissecting microscope for the presence of trematode larvae. Drawings and measurements of the parasites were made from living specimens under moderate cover-slip preessure and measurements are given in millimeters.

RESULTS

A single species of cercaria was found and is described below:

Description

Body of cercaria (Fig. 1) 0.24 to 0.26 long and 0.03 to 0.07 wide. Undulating fin present, inserted on dorsal surface of body above body of anteriormost mid-

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body penetration gland, and terminating posteriorly midway between intestinal crura and excretory bladder. Five pairs of penetration glands (Fig. 2) staining light pink with neutral red, situated lateral to esophagus, their ducts extending forward and opening medially into slightly subterminal suckerless oral cavity. Esophagus 0.12 to 0.15 long and straight, extending just into posterior half of body then branching into two relatively short intestinal crura, each 0.01 to 0.03 long, staining pink with neutral red. Excretory bladder "V" shaped and 0.02 to 0.04 in height. Collecting tubules extending anteriad to fork of intestine then branching into two finer collecting tubules. Three pairs of flame cells occurring in positions shown in Figure 2. Integument on anterior half of body minutely spinose, spines coarser on penetration organ. Posterior half of body and tail aspinose. Tail stem 0.28 to 0.39 long and bearing two symmetrical furcae 0.06 to 0.14 in length, each with lateral fins arising at base of furcae and confluent around furcal tips. Lateral fins not extending anterior to tail fork. Median excretory tubule extending from opening of excretory bladder and branching with caudal furcae, opening at each furcal tip.

Sporocysts (Fig. 3) pale white, 0.23 to 0.35 long and 0.11 to 0.21 wide, containing up to seven discernible cercariae and two to four additional germ balls. Sporocysts appearing a pale white mass in gonad of host clam. No host gametes seen, indicating parasitic interference with gamete production since uninfected clams of comparable size contained mature eggs and sperm. This cercaria is named after its molluscan host.

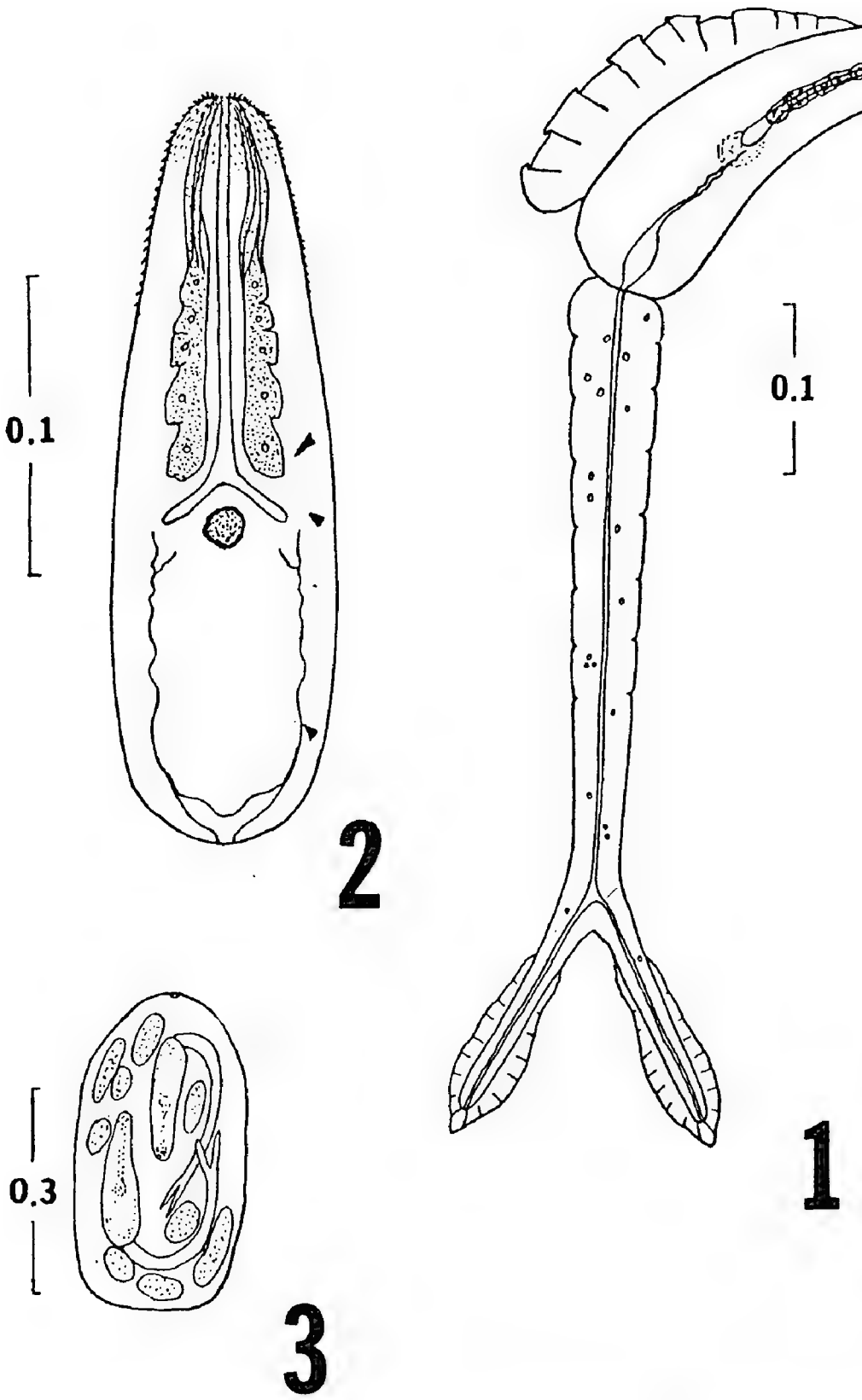
Host: *Mercenaria campechiensis* (Gmelin), southern quahog

Locality and Incidence: San Luis Pass 3 of 5 clams (60.0%); Terramar Beach, 5 of 23 clams (21.7%). Both sites are on the north shore of the western portion of Galveston Island.

Seasonality: All infected clams were taken during the month of August. Six clams from Terramar Beach in March were not found to be infected.

Host Size: The eight infected clams ranged in size between 46 and 70 mm (maximum shell dimension) averaging 53.8 mm. The twenty uninfected clams examined from the two stations where the parasite was found ranged in size from 57 to 114, averaging 90.5 mm.

Cercaria mercenariae most nearly resembles *Cercaria loossi* Stunkard, 1929 in the possession of five pairs of penetration glands, three pairs of flame cells, a V-shaped excretory bladder, and symmetrical caudal furcae whose lateral fins are confluent around the furcal tips. It differs from *C. loossi*, however in lacking a swelling of the excretory duct in the anterior portion of the tail stem, and in that the lateral fins of the caudal furcae of *C. mercenariae* do not extend anterior to the tail fork as they do in *C. loossi*. Four species of adult aporocotylids have been reported from marine fishes in the Gulf of Mexico. Two of these were reported from host species which Parker (1965) lists as being present in Galveston Bay. *Cardicola laruei* Short, 1953 parasitizes the heart of *Cynoscion nebulosus* and *C. arenarius*. Both of these fishes are found throughout the year in all parts of the Galveston Bay system. *Selachohemecus olsoni* Short, 1954 inhabits the heart of



FIGS. 1–3. Larval stages of *Cercaria mercenariae* from *Mercenaria campechiensis*. 1. Lateral view of body of cercaria, with caudal furcae rotated 90° around axis of tail stem to present dorso-ventral view. 2. Ventral view of body of cercaria. Flame cells omitted from right side. 3. Sporocyst.

Rhizoprionodon terraenovae (as *Scolidon*) a small shark which according to Parker (1965) is a rare summer visitor to West Bay.

Cercaria mercenariae was found only in clams from the high salinity (25–30%) portion of West Bay along the western part of the north shore of Galveston Island during the month of August. The same species of clam was also found

living in the sand beyond the surf zone along Galveston Beach, but twenty clams from those habitats were examined and not found to be infected.

In view of the geographical and seasonal correlation of the occurrence of *Rhizoprionodon terraenovae* and the aporocotylid infections of *Mercenaria*, this shark appears more likely to be the definitive host than the two species of *Cynoscion* cited above, which are less restricted in habitat and seasonality.

This is the first known record of a cercaria developing in clams of the genus *Mercenaria*. *M. campechiensis* is of a limited use on the western Gulf Coast as a human food source, but its relative, *Mercenaria mercenaria*, the northern quahog or hard clam, is a commercially important species on the U.S. East Coast. The larger adults are harvested for use in chowder and the smaller ones are marketed as "cherrystone clams" and meats are consumed whole. The only other trematode reported from quahogs (*Mercenaria*) is the metacercarial stage of an echinostome described as *Himasthla muehlensi* by Vögel (1933) in New York. This parasite was reported to be capable of infecting humans.

ACKNOWLEDGMENTS

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LARVAL SPOTTED SEATROUT (*CYNOSCION NEBULOSUS*) A BIOASSAY SUBJECT FOR THE MARINE SUBTROPICS[1]

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ABSTRACT

Larval spotted sea trout were selected as the test subject because specimens can be produced under laboratory conditions throughout the year by adjusting the temperature and photoperiod. Tests were made to determine the sensitivity of spotted sea trout larvae to water samples from different environments and to Baton Rouge No. 2 fuel oil. Considerable variation in water quality was found within a small area with regard to larval mortality. Sublethal fuel oil concentrations (0.00–1.00 ppm) produced a general decrease in total body length and critical distance. An increase in unpigmented eyes occurred with an increase in fuel oil concentrations.

INTRODUCTION

A major problem in assessing habitat quality in the estuarine environment is to relate the method of analysis to economically important species. Lasker (1975) demonstrated the usefulness of using laboratory-spawned fish larvae (*Engraulis mordax*) for estimating the food value of various water mass off of southern California for this species. Other larvae such as those of bivalves have also been used to evaluate marine habitats (Woelke, 1961).

The spotted seatrout (*Cynoscion nebulosus*) is one of the most important commercial and recreational fish in the Gulf of Mexico area (U.S. Dept. of Commerce 1975 and Deuel 1973). This fish is dependent on the estuarine habitat for spawning and nursery grounds (Tabb 1966). In this report, we present evidence

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of the usefulness of larval spotted sea trout for detecting degraded areas in an estuary and more specifically the evaluation of the effects of fuel oil (water-soluble fraction).

The impact of crude oil has been investigated with regard to several crustacean and fish species (Wells and Sprague 1976; Mills and Culley 1972; Eisler and Kissil 1975; Heitz *et al.* 1974; Stegeman 1974; and Dunning and Major 1974). Additional information is available on the effects of fuel oil components on microalgae (Winters 1976). Very little information is available on the effects of sublethal levels of oil on larval marine fish. Struhsaker, *et al.* (1974) found that benzene, a component of crude oil, caused high mortality and abnormal larval development in herring after exposure in the egg and larval stages.

MATERIALS AND METHODS

The selection of larval spotted seatrout as the test subject was made because of the ability to have specimens produced under known conditions throughout the year. These larvae were from spawns obtained by adjusting photoperiod and temperature following the methods of Arnold, *et al.* (1976). Under this method spawning occurs at night (6 p.m.–10 p.m.) and the eggs float into collection boxes, where they are available for use the next morning. Depending on temperature, hatching of the eggs occurs 12 (35°C) to 18 (25°C) hr after spawning. This incubation period provides time for obtaining the water samples to be tested. In order to determine if spotted seatrout eggs and larvae were sufficiently sensitive to detect changes in microhabitat, water samples were collected within a five-mile radius of the National Marine Fisheries Service Laboratory at Port Aransas, Texas. The sample locations were selected to cover a diverse range of conditions (Table 1). Water samples were returned to the laboratory in sealed one-liter glass jars and aerated to produce a uniform dissolved oxygen concentration (5.2 ppm) which remained constant throughout the test period. The pH of the seawater samples ranged from 7.8 to 8.2. All samples were collected and tests begun within a two-hour period. The water samples were divided into 100 ml glass jars and one-hour posthatched larvae were gently placed into the samples. Each jar contained 30–50 individuals. All tests were run at 31°C. Tests were terminated after 24 hours of exposure to the water samples. Four tests were made for each water sample.

The response of larval spotted seatrout to fuel oil (water-soluble fraction) was tested. Larvae (one-hour posthatch; 19-hour after spawn) were placed in 100 ml beakers containing test solutions. Fifty larvae were placed in each beaker. Tests were run in duplicates from two separate spawns.

The fuel oil tested was Baton Rouge (Louisiana) No. 2 obtained from Dr. Van Baalen, University of Texas, Marine Science Institute, Port Aransas, Texas, who gives a detailed analysis of the water soluble fractions of this oil, and the oil-seawater stock was prepared following Winters, *et al.* (1976). Dilutions of the oil-seawater stock were made serially and the concentrations reported are based on volume/volume measurements (ppm). All dilutions were made with filtered seawater from the spawning tanks (25°C, dissolved oxygen 6.2 ppm, salinity 30 ‰).

All tests were run at 25°C for a period of 48 hours. Visual observations of the larvae were made at the end of the 48-hour period. At this stage of development they will not move rapidly; however, they will show an avoidance response to a predatory object. The larval critical distance was tested by using a dissecting needle moving perpendicularly in the water column at a speed of 1 mm/sec toward the eye of the larva. The closest distance (mm) between the needle and the larva before larval movement (avoidance response) was recorded as the critical distance.

TABLE 1.

Mortality of larval spotted seatrout after 24-hr exposure to various water sources.

Location Number	Type of Location	Temperature (°C)	Salinity (o/oo)	% Mortality[1] Mean of four tests	Remarks
1	Boat harbor off shrimp processing plant	32	25	47.7 (43.6-51.2)	Boats Unloading
2	Boat harbor off fuel dock	31	25	49.5 (48.6-50.0)	Oil slick
3	Boat harbor off supply company in dead end of harbor	31	20	70.3 (62.2-81.4)	----
4	Boat harbor mid-channel	31	25	48.5 (45.3-51.6)	Oil slick
5	Boat harbor entrance	31	26	33.8 (29.0-36.1)	----
6	Intracoastal Waterway - 0.8 km from chemical plant	31	21	15.5 (10.0-20.3)	----
7	Intracoastal Waterway - mouth of boat channel to housing development #1 (permanent residence)	31	21	97.5 (92.2-100.0)	----
8	Housing development #1 (permanent residence) mid-channel dead end	31	21	90.0 (86.2-92.1)	----
9	Intracoastal waterway - mid-channel	32	24	27.2 (24.1-30.0)	----
10	Oil dock	31	27	8.8 (7.0-10.5)	Setting piling poles
11	Housing development #2 (seasonal occupancy) mid-channel	31	27	21.0 (20.5-21.8)	----
12	Small pleasure boat harbor	31	27	48.2 (46.6-50.0)	Trace of oil
13	Small pleasure boat harbor - dead end	31	30	47.5 (45.4-50.0)	Trace of oil
14	Small pleasure boat harbor - fuel dock	31	27	23.0 (20.2-25.6)	Oil slick
15	Aransas Channel mouth	30	28	0.5 (0.0-1.9)	----
16	National Marine Fisheries service dock	31	27	0.8 (0.0-3.1)	----
17	Ferry Landing	31	27	4.2 (2.9-5.0)	----
18	Ocean beach	30	28	0.6 (0.0-2.4)	----
19	Aransas Channel 1.6 km in from mouth	31	27	2.2 (0.0-5.6)	----
CONTROL	FILTERED SEAWATER - FROM SPAWNING TANK	31	28	1.6 (0.9-3.6)	----

[1]Mortality range of four tests in parentheses.

RESULTS AND DISCUSSION

The results of the microhabitat evaluation study are summarized in Table 1. Within the five-mile radius of Port Aransas, Texas, considerable variation in water quality (with regard to larval mortality) was found. The mean percentage mortality varied from a high of 97.5 (location 7—off a housing development) to a low of 0.6 (location 18—open-ocean beach). The variation found within the area indicates a need for in depth evaluation of estuarine developments. Larval spotted sea trout appear to be a suitable test subject for detecting microhabitat differences.

The results of the study of sublethal effects of fuel oil (water-soluble fraction) are summarized in Table 2. There was a general decrease in total body length and critical distance with exposure to oil (water-soluble fraction). The percentage of larvae with unpigmented eyes increased with increased oil concentration.

Similar effects were reported by Wilson (1976) on the application of oil dispersants on developing embryos of herring, plaice, and sole. Very little is known as to the physiological effects of petroleum hydrocarbons on fish. Roubal (1974), using spin label techniques, showed that hydrocarbons preferentially invade neural tissues. This may explain the loss of sensitiveness, indicated by reduced critical distance, by larval sea trout after exposure to fuel oil. Struhsaker

TABLE 2.

Summation of the effects of fuel oil (water soluble fraction) on larval spotted seatrout.

Oil Concentration (ppm)	% Mortality	% Distorted Larvae	% Unpigmented Eyes	Total Body Length (mm)	Body Depth (mm)	Critical Distance (mm)
1.00	5 [1]	22.9	27.5	1.79	0.51	0.35
	(0-6)[2]	(16.7-30.0)	(20.0-42.8)	(1.60-1.93)	(0.49-0.53)	(0-3)
				{0.10}[3]	{0.02}	{0.64}
0.10	3	18.7	26.1	1.82	0.55	0.49
	(0-6)	(12.3-24.1)	(12.5-40.0)	(1.58-1.98)	(0.45-0.58)	(0-2)
				{0.11}	{0.01}	{0.66}
0.01	3	0	12.0	1.76	0.54	0.82
	(0-5)		(10.0-15.4)	(1.62-1.95)	(0.46-0.59)	(0-3)
				{0.09}	{0.02}	{0.08}
0.00	5	0	0	2.25	0.58	0.94
	(0-6)			(2.05-2.35)	(0.54-0.60)	(0-2)
				{0.05}	{0.01}	{0.70}

[1]MEAN

[2]RANGE

[3]STANDARD DEVIATION

et al. (1974) reported that herring larvae were lethargic after exposure to benzene. Benzene is a major component of Baton Rouge No. 2 fuel oil (water-soluble fraction) according to Winters *et al* (1976); thus our findings and those of Struhsaker *et al.* may be comparable, although many additional organic compounds are also present in fuel oil.

Winters *et al.* (1976) found that Baton Rouge fuel oil (water-soluble fraction) was relatively non-toxic to microalgae and concluded that probably small amounts of specific components in the oil were responsible for the toxic effects and not the total amount of water solubles. They also suggested, and we agree, that one cannot make broad generalizations as to the detrimental effects of fuel oil on organisms. This specific type of oil tested while non-toxic to microalgae appears to be very detrimental to larval sea trout.

CONCLUSION

Considerable variation in water quality (with regard to larval mortality of spotted seatrout) was found within a relatively small area (5-mile radius). When larval spotted seatrout were subjected to sublethal concentrations of fuel oil (0.00–1.00 ppm), there was a general decrease in total body length and critical distance, while the percentage of larvae with unpigmented eyes increased with increased oil concentration.

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PETROLEUM IN DEEP BENTHIC ECOSYSTEMS OF THE GULF OF MEXICO AND CARIBBEAN SEA

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ABSTRACT

Petroleum hydrocarbons were analyzed from 74 bethic tar samples collected between 1967 and 1973 in the Gulf of Mexico in depths ranging from 180–3843 m and from 12 stations in the Caribbean Sea in depths of 522–4557 m. Chemical analyses showed the tars to contain no volatile hydrocarbons in the range of C_{10} to C_{40}, to be highly asphaltic, low in paraffins, and unusually high in sulfur, vanadium and nickel.

Evidence is presented for natural petroleum seeps from several areas in the western Gulf of Mexico, including salt diapirs (Vema Knolls), and from an area of ironstone deposits in the northeastern Gulf. Specimens of the starfish, *Persephonaster echinulatus*, from a southwest Gulf of Mexico station were found engulfing and solubilizing tar lumps. Plant material, often of terrestrial origin, was found in 56% of the Gulf of Mexico tar stations and 100% of the Caribbean tar stations. A rich and varied bottom fauna was found associated with stations yielding large amounts of plant material and oil.

INTRODUCTION

Paucity of Benthic Tar Samples

A substantial number of publications dealing with the distribution and amounts of petroleum hydrocarbons in the marine environment has appeared since the paper on floating tar by Horn, Teal and Backus in 1970. Sufficient information is now available to conclude the pelagic oils are nearly if not truly cosmopolitan in their occurrence. For example, the literature covers parts of the Pacific Ocean (Wong, Green and Cretney 1973); areas around Bermuda and in the Sargasso Sea of the Atlantic Ocean (Butler, Morris, and Sass 1973); and in the Gulf of Mexico and Caribbean Sea (Jeffrey, Pequegnat, Kennedy, Vos and James 1974). By comparison, there seems to be a paucity of reports on the occurrence of oil in the benthic environment, especially in the deep waters of the open ocean beyond the continental shelf.

It is assumed that most of the benthic tar that the senior author dredged in the deeper parts of the Gulf of Mexico, especially in the southwestern quadrant south of 24°00′N latitude, originated *in situ* from natural seepage. Although this is difficult to prove, there are several pieces of indirect evidence that support our assumption. As noted by Wilson *et al.* (1973), the limited record of proven submarine seeps, even in shallow offshore waters, is likely due to (1) difficulty of

FIG. 1. Bottom photo taken in 1971 of a natural seep located near the top of Vema 3 Knoll (a salt diapir) at a depth of about 3325 m in the Gulf of Mexico. The compass and vane in upper right of photo measure 7.5 cm in height and 34 cm in length. The white crustacean near photo center is *Munidopsis columbiana*. This is the only Gulf collection site of this species in spite of repeated dredgings around the knoll. Elsewhere it is known only from the deep Colombian basin in the Caribbean. Note crinoid in lower right. An analysis of the 50-gallon sample recovered from this site by dredge is shown in Tables 1 and 2.

observation and (2) to less extensive exploration of offshore areas compared with onshore areas. Even so, a report of the National Academy of Sciences (1975) estimates that about 10 percent of the petroleum hydrocarbons found in the marine environment have come from natural oil seeps. Koons and Monaghan (1976) note that these offshore flows form tar mats on the ocean floor. Similar conceptions of the structure of the tar masses resulting from submarine seeps are projected by Kolpack (1971) and by Jeffrey *et al.* (1973). Our findings in the deep Gulf of Mexico also supported the mat-like conceptualization of the seepage. In particular, we were fortunate to take bottom photographs of large seeps on or near the top of a submarine knoll at depths over 3,100 m in the southwestern Gulf of Mexico (Fig. 1). As is pointed out later, some of these larger seeps appear to structure an otherwise featureless environment so as to attract some demersal fishes and perhaps some of the more mobile invertebrate epifauna. Some of the larger tar masses brought to the surface measure up to $20 \times 15 \times 9$ cm and have striations on them that appear to have been made during extrusion through the sediment bed.

Interestingly enough, the Mexican government recently announced the discovery of a huge oil pool several kilometers shoreward of the most productive tar stations that we dredged in August of 1969.

A study of the results of a dredging and trawling program carried out by the senior author aboard Texas A&M University's R/V ALAMINOS revealed that

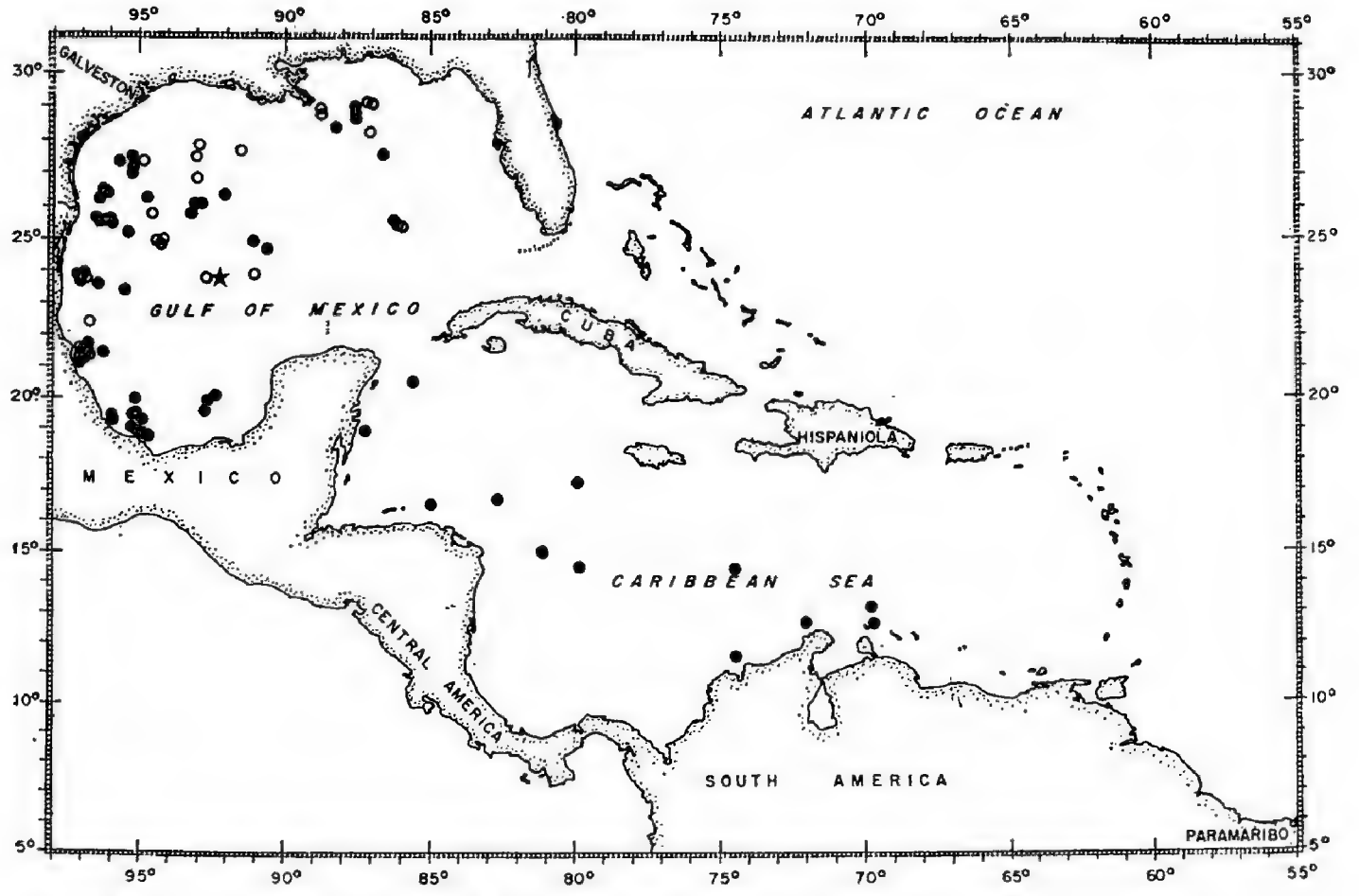

FIG. 2. General distribution of R/V ALAMINOS stations where benthic petroleum hydrocarbon samples were dredged between 1967 and 1968. Some circles cover more than one station. Solid circles indicate where plant and oil were taken; open circles indicate oil only. The star marks the approximate location of the Vema 3 Knoll.

over 100 samples of oil and tars had been brought up from benthic environments of the Gulf of Mexico and Caribbean Sea between 1969 and 1971. In fact, it was ascertained that out of the 188 trawl and dredge stations mounted in the Gulf and Caribbean between offshelf depths of 180 and 4160 m, 96 contained some oil or tar. Moreover, those having the largest amounts were located in the western Gulf of Mexico south of 24°N latitude and west of 94°00W longitude, with the exception of the Vema 3 knoll. This knoll, which is located in the southwestern Gulf, is described by Worzel, Leyden and Ewing (1968). To our knowledge, the picture presented here of the Vema 3 seep (Fig. 1) is the only documented oil seep reported on the sediment surface from offshelf waters of the Gulf of Mexico.

Objectives

In accordance with the above, the present paper is devoted to (1) depicting the distribution of petroleum hydrocarbons in the deep benthic areas of large parts of the Gulf of Mexico and the central Caribbean Sea, (2) analyzing the chemical characteristics of representative samples of the tar, (3) indicating the probable sources of some of the tar and (4) documenting observations on a record of the engulfing of benthic tar by a starfish.

SAMPLING

Gulf of Mexico

From 1969 to 1971 some 74 bottom samples of tar were collected during seven oceanographic cruises of Texas A&M University's R/V ALAMINOS. Samples were collected as part of a biological sampling program utilizing either the Benthic Skimmer (Pequegnat, Bright and James 1970) with a gape of 3 meters or with a 20-meter otter trawl which is estimated to have an effective collecting gape of 12 meters. All of the stations yielding petroleum in the Gulf were located in water ranging in depth from 180 to 3843 m (ave. 1550 m) on the continental slope and rise or on the abyssal plain.

Although benthic tar was found in all geographic regions of the Gulf, its frequency of occurrence in dredge samples ranged, as follows: 61 percent of total dredges in the southwest Gulf, 41 percent in the northwest, 23 percent in the northeast, and only 8 percent in the southeast (see Fig. 2). A map showing the worldwide distribution of submarine seeps (Koons and Monaghan 1976) indicates that the western Gulf has the largest concentration of seeps in the Gulf.

Caribbean Sea

In 1970 some 22 dredge stations were mounted in the Caribbean on an irregular line from the Yucatan Channel on the north and Curacao to the south (see Fig. 2). Twelve of these stations or 55 percent yielded tar from depths ranging from 522 to 4557 m. The percentage frequency of occurrence increased substantially south of 18°N latitude. The map by Koons and Monaghan referred to above agrees with this observation.

CHEMICAL ANALYSIS OF BOTTOM TARS

Analytical Method

Ten of the tar samples dredged from the bottom of the Gulf of Mexico were analyzed by the junior author for saturated hydrocarbons by gas chromatogra-

phy, compound type composition (i.e., percent paraffins, aromatics, NSOs and asphaltenes) by column chromatography on silica gel and alumina, molecular size by gel permeation chromatography, sulfur content by the Leco combustion method, and vanadium and nickel by activation analysis.

Results of Hydrocarbon Analyses

Gas chromatography of these tars showed that there were no volatile hydrocarbons in the range of C_{10} to C_{40}, that is, no spikes appeared on the chromatograms. The tars were highly asphaltic with an asphaltene content in the range of 40 to 69 percent (see Table 1 for compound type composition and molecular weight). The tars were unusually low in paraffins (1.3 to 6.3 percent) and contained variable amounts of high molecular weight aromatics and NSOs. Gel permeation chromatography showed that these tars had an average molecular size of 4000 to 6000, which is higher than the normal floating or beach tar, unless it had been highly weathered for a long period of time. These data seem to indicate that these bottom tars are residues of a highly asphaltic petroleum or asphalt that may have been weathered by chemical and biological means for a long time.

Sulfur and Metal Analyses

Total sulfur content of each of these tars was unusually high, being in the range of 3.6 to 8.4 percent total sulfur (see Table 2 for percent sulfur and ppm

TABLE 1

Compound type and average molecular size of bottom tars from the Gulf of Mexico. Vema 3 knoll is located at 23°47′N, 92°27.9′W at a depth of 3325–3330 m.

LOCATION	% SATURATES	% AROMATICS	% NSOs	% ASPHALTENES	AVERAGE MW
23°49'N 96°53.8W	1.3	8.3	23.6	66.8	6035
21°21.4'N 96°42.8!W	6.1	13.9	36.1	43.9	6498
21°30.3'N 96°11.7'W	4.5	14.6	21.5	59.4	6123
21°41.1'N 96°51.0'W	4.9	7.0	8.7	79.4	4378
21°45.0'N 93°15.0'W	5.8	17.7	18.9	57.6	5093
Vema 3 Knoll (hard)	2.0	23.9	18.9	55.1	5912
Vema 3 Knoll (soft)	3.1	27.4	24.6	44.8	4391
Vema 3 Knoll (very soft)	6.3	28.3	24.6	40.8	4245
23°49.0'N 96°59.0'W	ND	ND	ND	69.4	6169
23°49.0'N 96°59.0'W	NP	ND	ND	60.8	4472

vanadium and nickel). The vanadium and nickel ratios were also unusually high, ranging from 479 to 1200 ppm for vanadium and from 37 to 135 ppm for nickel. The V/Ni ratio was quite variable, however, ranging from 3.7 to 14.0, and no two samples appeared to be exactly alike.

SOURCES AND AMOUNTS OF BOTTOM TARS

It is not possible to account with certainty for the origin of the petroleum hydrocarbons at all stations from which they were collected, as the chemical properties measured thus far do not provide definitive clues as to the source of these bottom tars. There seems little doubt, however, that the Vema 3 deposit is a seep and, as will be noted later, the material in the ironstone region of the eastern Gulf is located in the sediment bed in a manner that would be difficult to explain had it been deposited by sinking from the surface. This leaves as uncertain the origin of the extensive finds in the western Gulf of Mexico. We believe that most of this western material must have come from seeps, simply because at some stations there was far too much of it in very large chunks to have been accumulated from tar balls. Moreover, a large percentage of the oil produced in Mexico has higher than normal sulfur and asphaltene content, as do our samples, suggesting that the bottom tars may well have seeped from similar formations under water.

Ridge Systems Find

Our findings point to the likelihood of seeps in the ridge system off the Gulf Coast of Mexico in the vicinity of (1) 23°28.8′N, 97°12.5′W (677 m depth) and (2) near 21°30′N, 96°40′W off Laguna Tamiahua, which is itself the site of a very large and active shore seep. According to Yuill (1973) the lagoon extends north-south some 60 miles, approximately from latitude 22°05′ to 21°06′N and is about 14 miles across at its widest point. The oil seep itself is located about two miles north of San Geronimo at 21°33′30″N and 97°38′00″W. This positions one of our largest discoveries of benthic tar directly offshore from the Tamiahua seep. It should be noted, however, that the ridge system, whose components run north-south virtually parallel to shore, almost certainly acts as a series of baffles preventing benthic materials from moving out from shore to the 1025 m isobath where large quantities of tar were dredged. In fact, between latitudes 21° and 24°N and in a strip of bottom delimited by the 1000 and 1370 m isobaths the amount of tar taken averaged between 5 and 20g per square meter. Several trawls yielded over 100 kilos of tar in chunks measuring up to $20 \times 30 \times 9$ cm.

The Tamiahua Seep

Yuill (1973) indicates that the origin of the Tamiahua seep is uncertain, but the general consensus of the local residents is that the tar has been there over 50 years which, for that area, almost certainly precludes any man-made cause. The amount and widespread distribution of the oil in the above band leads us to the same conclusion about this deep-benthic source.

TABLE 2

Sulfur, vanadium, and nickel composition of bottom tars. Vema 3 knoll is located at 22°47′N, 92°27.9′W at a depth of 3325–3330 m.

SAMPLE LOCATION	% TOTAL SULFUR	VANADIUM (ppm)	NICKEL (ppm)	V/Ni
23°49.0'N 96°53.8'W	6.0	635	114	5.6
21°21.4'N 96°42.0'W	6.6	720	101	7.1
21°30.3'N 96°11.7'W	3.8	803	82	9.8
21°41.1'N 96°51.0'W	4.1	1220	87	14.0
21°45.0'N 93°15.0'W	8.4	479	116	4.1
Vema 3 Knoll (hard)	7.3	852	85	9.7
Vema 3 Knoll (soft)	6.5	833	135	6.3
Vema 3 Knoll (very soft)	6.5	539	87	6.9
23°49.0'N 96°59.0'W	3.6	136	37	3.7
23°49.0'N 96°59.0'W	8.1	1058	104	10.2

Salt Diapir Seep in Western Gulf

An even more certain natural seep is located near the top of Vema 3 Knoll (23°47′N, 92°27.9′W) at a depth of 3325–3330 m. The extruded oil on this salt diapir was photographed by the senior author in 1971 (see Fig. 1). In 1973 we were able to dredge a sample of this material, the analysis of which is seen in

Table 1. In this connection, we may note that geologists aboard R/V ALAMINOS in 1969 obtained petroleum hydrocarbons from similar diapirs in three sediment cores taken by means of both a Phleger Corer and a piston corer at 21° 45.0′N and 93°15.0′W (Bouma, Rezak and Jeffrey 1969). The coring depths ranged between 2600 and 3000 m. In all cases the hydrocarbon material was found anywhere from 5 to about 200 cm below the core top. These authors concluded that the hydrocarbons were obtained from a seep or series of seeps on the deep ocean floor. The site of this find is approximately three miles southwest of the seep pictured in Fig. 1. Data from the analysis of the Bouma material is presented as item 5 in Table 1.

Petroleum Association with Ironstone

Oil was also taken in conjunction with an ironstone deposit (see Pequegnat, Bryant, Fredericks, McKee and Spalding 1972) in the northeastern Gulf of Mexico (25°31′N, 86°13′W) at a depth of about 3175 m under the East Gulf Loop Current. The fact that the petroleum formed a thin layer underneath the ironstone crust points to seep origin.

BIOLOGICAL EFFECTS OF CONCURRENCE OF PLANT MATERIAL AND PETROLEUM

An average of 56 percent of the stations yielding benthic tar in the Gulf (most in the western part) and 100 percent of those in the Caribbean were a source of plant remnants as well. Much of the plant material was of terrestrial origin, although occasionally shallow water vegetation (e.g., turtle grass) was found. In only two instances was sargassum weed a part of the sample. In no case was the petroleum material attached to the plant remnants in any way. Interestingly, stations with a large yield of plant material and petroleum also possessed a comparatively rich and varied bottom fauna (Tables 3 and 4). Stations in Table 3 where plant materials and tar were taken supported twice as many species and many times the individuals found at the stations where neither plant remains nor tar were found. The effects on demersal fish populations were even greater (Table 4). Station 71A8-60 had much more plant material than 69A11-86, a fact that may account for the substantial differences between their fish populations. Very likely the structuring of the otherwise featureless bottom environment serves as important habitat for animals, especially the fishes.

The significance of the concurrence between tar seeps and plants is not known. Very likely most of the plant material, especially in the ridge system, was carried there by the north-flowing current in that region. During the rainy season (July–August) on the land bordering the southwestern extension of the Gulf (around 18°N latitude, 92–95°W longitude), large masses of terrestrial and pond vegetation are carried by swollen rivers into the Gulf. The prevailing current, flowing first westward, turns northward off Veracruz and flows steadily to the Texas Coast. Plant material sinks deeper and deeper with time. By the time the water reaches the ridge system (21°N), the current must be the principal source of plant remains found in the valleys of the ridge system along with the tars.

The presence of the series of ridges and valleys, paralleling shore and occurring in successively deeper water, as well as the nature of the water flow effectively cut off the adjacent land as a source of vegetation found in our samples. Most of it must certainly have come from the south in the southern reaches of the Bay of Campeche.

It seems likely that some of the invertebrates use this plant material directly as food (e.g., the sea-urchins *Plesiodiadema antillarum* and *Phormosoma placenta*, Station 69A11-86, Table 3), whereas others such as holothurians and a host of other smaller organisms utilize the detritus produced by the decaying vegetation. Other species of macrofauna appear to make some use of the petroleum as food.

OBSERVATION ON BIOLOGICAL UTILIZATION OF TAR

At one station off Mexico (21°16.2′N, 96°51.9′E; depth of 567 m) the senior author dredged (among other species) 24 specimens of the asteroid *Persephonaster echinulatus* (order Phanerozonia, suborder Paxillosa, family Astropectinidae). Substantial quantities of tar (20 kilos) of various consistencies were also taken in the same haul. Subsequent laboratory study revealed that four of these asteroids were in the process of solubilizing small cubes of tar in individual gastric pouches extending from the stomach wall. The tar cubes, which measured about 4 mm on edge, were tightly encased in the cupped ends of projections from the gastric wall that resembled inverted ends of glove fingers. When the cubes were gently removed from these fimbriae, the enclosed part of the cube was markedly smaller and its surface was as smooth as if melted—a marked contrast to the roughened surface of the uncovered portions. Samples of the material were readily soluble in benzene. Since this species is a selective bottom feeder, it is unlikely that the tar was an accidental part of the diet. Starvation was certainly not an element in the action, for in addition to the tar, the four asteroids had a total of 4 paleotaxodont bivalves, 32 gastropods, and fragments of crustacean (cumacean) skeletal components in their completely packed stomachs (Table 5).

Asteroids in general and *Persephonaster echinulatus* in particular are not common in the deep waters of the western Gulf of Mexico. Thus, the taking of relatively large numbers of specimens (24 as compared with an average haul of 2) when substantial quantities of benthic petroleum are also taken may or may not be significant, but one is tempted to speculate that the petroleum enriches its normal food supply either directly or indirectly. Teal (1976) found petroleum hydrocarbons in tissues of a sea cucumber and a galatheid crab taken at 25°N, 62°W in depths ranging from 5500 to 5800 m.

CONCLUSIONS

Petroleum hydrocarbons are a very common component of the deep benthic environment of much of the Gulf of Mexico and parts of the Caribbean Sea. Some of these oils and tars have come from man's contamination of pelagic

TABLE 3

Numbers of individuals per hectare of benthic invertebrates found at deep stations with and without plant debris and tar Southwest Gulf of Mexico.

SPECIES	STATIONS AND DEPTHS			
	With Plants & Tar		Without Plants & Tar	
	71A8-60 (1117m)	69A11-86 (1024m)	69A11-75 (1134m)	71A8-48 (1066m)
CARIDEAN DECAPODS				
Heterocarpus oryx	20	16	2	27
Glyphocrangon aculeata	14	6	2	1
Glyphocrangon nobilis	11	2	9	1
Glyphocrangon longleyi	--	--	--	--
Nematocarcinus rotundus	2	28	23	1
Acanthephyra purpurea	--	1	--	--
Plesionika holthuisi	--	2	--	--
Pontophilus gracilis	--	2	--	--
ISOPOD				
Bathynomus giganteus	--	1	--	1
ANOMURANS				
Parapaqurus pilosimanus	63	1	--	--
Munidopsis sigsbei	9	3	--	--
Munidopsis abbreviata	2	--	--	--
Munidopsis longimanus	1	--	--	--
Munidopsis nitida	1	--	--	--
Munida micropthalma	1	--	--	--
Munida valida	--	--	--	--
PENAEIDS				
Benthesicymus bartletti	2	10	4	1
Funchalia taaningi	1	--	--	--
MACRURA				
Stereomastis sculpta	16	6	7	29
ECHINOIDS				
Phormosoma placenta	--	281	2	2
Plesiodiadema antillarum	--	2690	--	--
HOLOTHURIANS				
Molpadia musculus	18	--	--	--
Molpadia barbouri	--	3	--	--
Mesothuria lactea	4	2	2	--
Benthodytes sanguinolenta	0	8	1	1
Paroriza prouhoi	1	--	--	--
Deima blakei	--	1	--	--

TABLE 3 (Continued)

SPECIES	STATIONS AND DEPTHS			
	With Plants & Tar		Without Plants & Tar	
	71A8-60 (1117m)	69A11-86 (1024m)	69A11-75 (1134m)	71A8-48 (1066m)
ASTEROIDS				
Midgardia xandaros	3	--	--	--
Nymphaster arenatus	--	2	--	2
Plinthaster dentatus	--	2	--	--
BIVALVES				
Nucula obliterata	--	2	--	--
Tindaria amabilis	--	11	--	--
SCAPHOPODS				
Dentalium laqueatum	--	3	--	--
Dentalium prolongum	--	48	--	--
Pulsellum pressum	--	10	--	--
CEPHALOPODS				
Ornithoteuthis antillarum	--	2	--	--
Vampyroteuthis infernalis	--	1	--	--
Neorossia sp.	--	10	--	1
TOTAL SPECIES	17	26	9	11
TOTAL INDIVIDUALS	169	3142	52	67

sources, but it is quite clear that where large amounts have been found, as on Vema 3 Knoll and off Tamiahua Lagoon, they are derived from natural seeps.

It is also apparent from bottom photographs and dredging results that some mobile invertebrate species opt to live upon petroleum seeps in deep water. Moreover, the combination of plant material and petroleum serves to create an important habitat for the macroepifauna, as judged from results of dredging. Also, there are some indications that where petroleum occurs in substantial quantities there is not only an enriched bottom fauna, but also that some species may well make some use of it as food. It is noted that a selective, bottom-feeding asteroid not only engulfs tar, but also solubilizes it, very likely in preparation for absorption.

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TABLE 4

Numbers of individuals per hectare of demersal fishes found at deep stations with and without plant debris and tar Southwest Gulf of Mexico.

SPECIES	STATIONS AND DEPTHS			
	With Plants & Tar		Without Plants & Tar	
	71A8-60 (1117m)	69A11-86 (1024m)	69A11-75 (1134m)	71A8-48 (1066m)
Stephanoberyx monae	13	3	--	--
Synaphobranchus oregoni	11	3	2	--
Nezumia hildebrandi	7	6	--	--
Gadomus longifilis	7	2	--	--
Bathygadus favosus	5	2	--	--
Dicrolene intronigra	2	1	5	--
Grenurus grenadae	3	2	--	--
Conocara macdonaldi	3	1	--	--
Monomitopus agassizi	2	2	--	--
Aldrovandia affinis	2	3	--	--
Halosaurus guntheri	2	2	--	--
Gadomus arcuatus	2	1	--	--
Scylliorhinus profundorum	2	--	--	--
Bathypterois quadrifilis	3	1	--	--
Bathygadus vaillanti	3	--	--	--
Cariburus mexicanus	2	1	--	--
Trachonurus sulcatus	2	--	--	--
Venefica procera	2	1	--	--
Hydrolagus alberti	1	--	--	--
Raja purpuriventralis	2	--	--	--
Squalogadus intermedius	1	1	--	--
Bathypterois longipes	2	--	--	--
Cariburus zaniophorus	1	1	--	--
Nezumia bairdii	1	--	--	--
Coryphaenoides sp.	--	1	--	--
TOTAL SPECIES	24	18	2	0
TOTAL INDIVIDUALS	101	34	7	0

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TABLE 5

Breakdown of materials found in the gastric pouch of 24 asteroids (*Persephonaster echinulatus*) taken at Station 71A8–40 at 21°16.2′N, 96°51.9′W, 567 m deep.

Starfish Size (mm) (arm tip-to-arm tip)	Bivalves		No. of Gastropods			Tar	Cumaceans
	Genus	No.	Genera	Species	Inds.		
74	*Nucula*	5 (6mm)	4	4	14	---	---
68	*Nucula*	1	3	3	14	tar	1
68	*Nucula*	4	3	4	11	nearly digested ---	1
	Paramusium	1					
78	*Nucula*	1	4	18	18	tar	---
	Limopsis	1					
72	*Nucula*	1	--	--	--	tar	---
64		--	1	1	8	---	---
			1 being digested				
54		--	8	8	16	---	---
46		--	3	3	24	---	---
66	*Cuspidaria*	1	3	3	16	---	---
56	*Nucula*	2					
	Limopsis (digested)	1	3	3	11	---	---
68	*Nucula*	1	2	2	14	---	---
76	*Nucula*	4	1	1	1	---	---
64		--	1	1	11	---	---
60	*Nucula*	1	4	4	21	---	1
58		--	2	2	13		
36		--	3	3	7	---	---
64	*Nucula*	1	2	3	3	---	2
50		--	--	--	--	---	---
30	*Nucula*	1	--	--	--	tar	---
48		--	1	1	1	---	---
46		--	3	3	8	---	---
33		--	2	2	6	---	---
68		--	3	2	15	---	---
66		--	5	3	10	---	---

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TROPHIC HABITS OF THE JUVENILE FISHES WITHIN ARTIFICIAL WATERWAYS— MARCO ISLAND, FLORIDA

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ABSTRACT

The present investigation was directed toward describing the trophic habits and factors which affect the distribution of juvenile fishes in a dredged residential canal of a Southwest Florida ocean-front development. The data presented provide a quantitative examination of both the spatial and temporal aspects of the more abundant species. A strong similarity was found between the trophic habits of fishes within the canals and published data for fishes of identical age classes from natural areas.

INTRODUCTION

Marco Island, on the southwest coast of Florida, has been the site of detailed ecological investigations into the structure and function of the local aquatic communities. These efforts were directed toward quantification of the potential impact attributable to extensive upland and waterfront development (Yokel 1974; Carter *et al.* 1973; Weinstein *et al.* 1977).

Trophic studies of juvenile estuarine fishes have produced a data base for species collected within natural bays dominated by marine seagrass or halophytic communities (Carr and Adams 1974; Brook 1977; Odum 1971; Harrington and Harrington 1961). The trophic habits and resource allocation have been shown to be functions of the temporal and spatial distribution of the fishes in those systems. In the present study the trophic aspects of juvenile fishes found within residential waterways were compared with the seasonality and cyclic abundance observed within natural estuarine habitat.

STUDY AREA

Marco Island, on the lower southwest coast of Florida, is the largest of the northern Ten Thousand Islands (position 25°57′N latitude, 81°32′W longitude, Figure 1). A large portion of the island's shoreline, formerly an intertidal mangrove (*Rhizophora*) forest, has been dredged and seawalled.

The waterways investigated were of the inland construction type (Lindall and Trent 1975). Collections were made within a five-year-old canal in the northern portion of the island. This

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waterway complex included a 1500-meter central canal and a number of short canals branching from its main axis. (Figure 1).

The Marco Island estuary has been described as seasonally hypersaline with low concentrations of dissolved nutrients (Weinstein *et al.* 1977). The predominant fish communities observed within both the natural and artificial habitats examined were marine in character and dominated by juvenile size classes (Weinstein *et al.* 1977; Yokel 1974).

The canals were generally low in turbidity (ranging from 2–10 JTU), however, a high degree of staining contributed by tannin compounds of the mangrove peat sediments resulted in a very high, light attenuation within the waterways. Water quality data indicate that low light penetration was a prime cause for the general absence of benthic attached vegetation within the canals (Weinstein *et al.* 1977). Macroalgae distribution consisted of isolated clumps of *Laurencia* spp. or small patches of *Caulerpa* spp. limited to the shallow berm edges during the warmer months.

MATERIALS AND METHODS

Fishes for food habit analyses were collected by a 7.1 m × 1.2 m × 0.74 cm minnow seine set along submerged portions of the canal berms, by three and five m headrope bottom trawls (5 min) of 4.45 cm stretch mesh body and 1.95 cm liner, by application of emulsified rotenone in 5 mg/1 concentrations along selected portions of seawall at high tide and in occasional collections by other methods; i.e. dip net. All fishes collected were immediately fixed in a 20 percent formalin/seawater solution and later transferred to a 40 percent isopropyl alcohol, tap-water solution.

Stomach contents were analyzed using the sieve fractionating technique as described by Carr and Adams (1972). This technique was adopted as the most equitable method of handling large numbers of stomachs in the size range of young-age class fishes reviewed. It also provided an effective method of determining the volumetric percentage composition of all food items while removing a source of observer bias for the larger food particles. All stomach content data have been presented in terms of preserved dry weight.

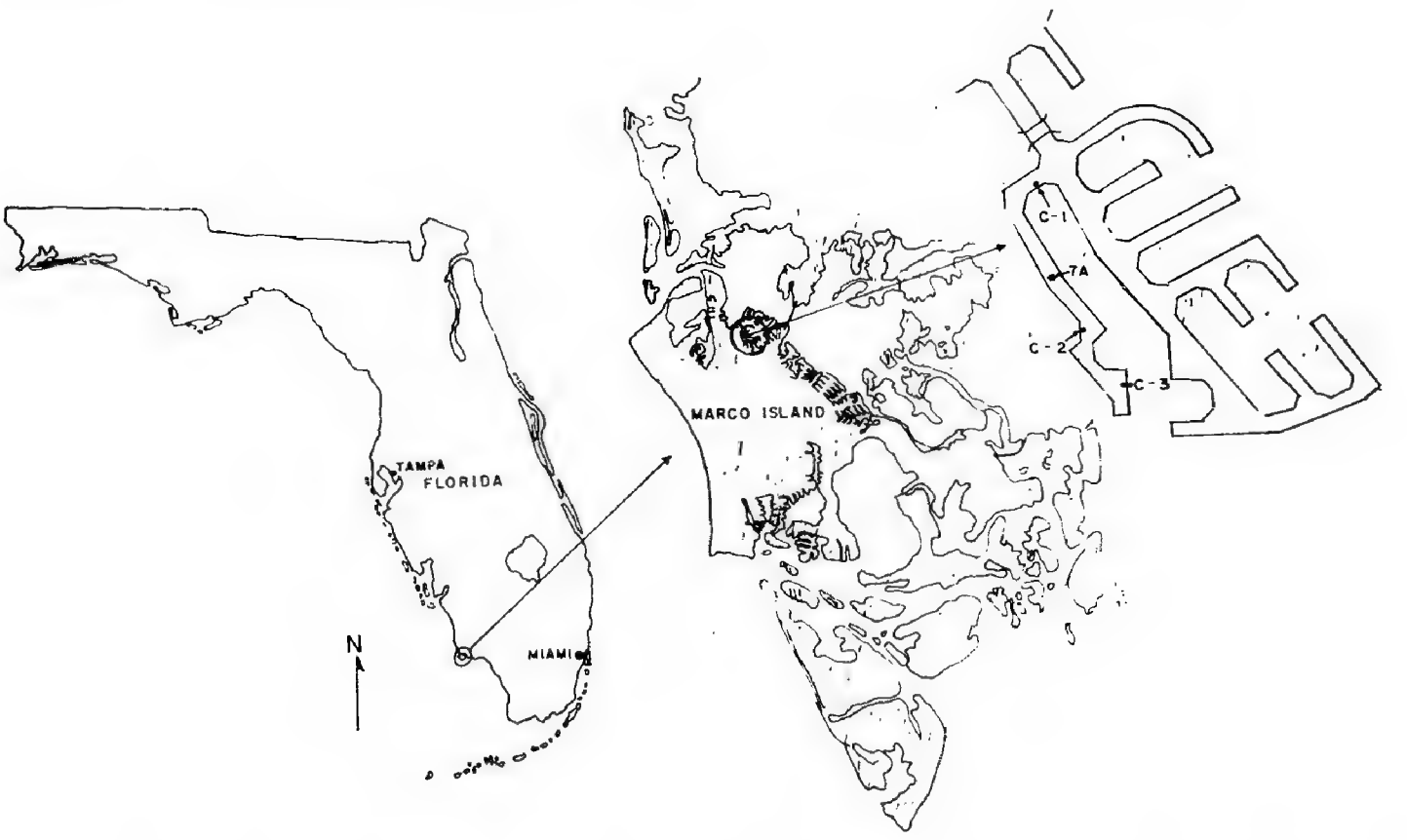

FIG. 1. Map showing location of Marco Island with an insert providing detail of the seine locations (c-1, c-2, c-3) and waterway complex sampled.

TABLE 1

Juvenile fishes collected by seine during Marco Canal sampling December 1974–February 1976.

Rank	% Total		# Months Recorded	Total Caught
1	70.3	*Anchoa mitchilli*	11	11,118
2	7.5	*Lagodon rhomboides*	10	1,234
3	6.4	*Eucinostomus argenteus*	14	1,065
4	4.9	*Harengula pensacolae*	6	816
5	1.7	*Eucinostomus gula*	12	286
6	1.7	*Opisthonema oglinum*	3	272
7	1.0	*Menidia beryllina*	6	171
8	0.8	*Anchoa cubana*	2	132

Field sampling was conducted over a 14-month period from November 1974 through January 1976. Sampling was restricted to a minimum distance of 150 m from the mouth of the canal. Most collections were concentrated in areas 350–1000 m into the waterway. The intent by this restriction was to minimize the collection of fishes which fed outside the canal. Collections were usually conducted during daylight hours.

All fishes collected for analysis were identified to species with the exception of the < 21 mm size class of the genera *Eucinostomus* and *Gobiosoma* where overlap of species characters made positive identification dubious. Standard length determined size class. Whole-fish weights presented were preserved wet weights.

Seine collection data were presented separately to examine seasonality and dominance observed in the juvenile fishes along the canal length. Seine stations were sampled by two adjacent net hauls monthly from December 1974 through February 1976. All collections were made perpendicular to shore during the forenoon coincident with low tide. Synchrony with low water was required for maximum exposure of shoal areas along the seawalls which provide area for seine deployment.

The dominance values presented were computed by the McNaughton Index (DI) expressed as

$$DI = \frac{n1 + n2}{N} \times 100$$

where n1 and n2 are the number of individuals in the first and second most abundant species in a sample and N is the total number in the sample (McNaughton 1967).

The diversity indices from the seine collections were based upon

$$H' = -\Sigma P(i) \log P(i)$$

where P(i) is the ratio of a single species to the total number of organisms collected (Shannon and Weaver 1949).

RESULTS

A total of 16,037 fishes representing 43 species was collected during the 14 months of seine survey. Six families dominated the catch and constituted 95.2 percent of the total (Table 1). These families in descending order of abundance were anchovies (Engraulidae), porgies (Sparidae), mojarras (Gerreidae), sardines (Clupeidae), silversides (Atherinidae) and gobies (Gobiidae).

Strong seasonality was exhibited as indicated by the dominance and diversity values (Table 2). The highest dominance value occurred during the period November–April coincident with the appearance of large numbers of juvenile *Anchoa mitchilli* and *Lagodon rhomboides*.

Food habits were examined for the most abundant juvenile species collected. The stomach content data (composited from all collection methods) for eleven species are provided in Tables 3 through 9. Data which represented collections from a single period were identified by the month of collection. Data were separated temporally or by size range when variations in diet were apparent between collections. The designation 'organic debris' referred to cases where the stomach contents fraction was animal in origin, but unidentifiable. Particular emphasis was placed upon documentation of ontogenetic shifts in the feeding habits of juvenile fishes examined.

The dominant species, *Anchoa mitchilli*, in the size range examined was characterized as a planktivore, consuming zooplankton (Table 3). Many of the copepods were identified as the common planktonic calanoid, *Pseudodiaptomus coronatus*. A secondary piscivorous habit was observed in the 40–50 mm fish. The presence of several categories of benthic fauna revealed benthic foraging as a major alternative energy source for the anchovy within the canals. Crab zoea appeared only during the summer and were utilized by a number of the size classes.

The smallest class of *Lagodon rhomboides* (11–15 mm) was also typified as a planktivore within the waterways. Benthic resources were relied upon to a greater degree in the larger size classes than observed in the anchovy. Amphipods and polychaete and oligochaete worms were of particular importance (Table 4). The increased consumption of algae in the larger sizes examined (36–70 mm) revealed an ontogenetic shift coincident with the seasonal increase in algal abundance.

The gerreids, *Eucinostomus gula* and *E. argenteus*, proved to be similar in dietary preferences. Benthic resources were of primary importance to these species (Table 5). Indistinct taxonomy prompted the combination of data for individuals of both species smaller than 21 mm. Fishes of the smallest size classes relied upon copepods and barnacles though benthic resources contributed significantly to the 16–20 mm fishes (Table 5). The preference for barnacle cirri and nauplii in the 6–10 mm fishes was attributed to the mouth size of this class and indicated an active selection of prey. Most copepods ingested were identified as of the benthic dwelling hapacticoid group. Similarity existed between the prey choices of the larger juveniles of the two species. The only notable difference was the higher percentage of oligochaetes in the stomach of the larger *E. argenteus* (25–80 mm). This proportion may be indicative of feeding area segregation between the two species.

The clupeids *Harengula pensacolae* and *Opisthonema oglinum* were abundant in the canal fauna during the warmer months (July–September). *H. pensacolae*, a planktivore feeding upon copepods and crab zoea, revealed a benthic dietary subsidy of amphipods and polychaete worms in the 26–35 mm fish (Table 6).

TABLE 2

Summary of seine data for Marco Canal, December 1974–February 1976[1]

	Dec.	Jan.	Feb.[2]	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Total fishes	4363	2909	163	667	517	377	383	872	1467	113	1886	660	770	897
Total (excluding *A. mitchilli*)	167	32	163	95	517	312	289	872	476	108	53	47	393	895
Total species	13	5	6	10	17	17	12	13	17	8	10	9	9	9
Diversity (H)	.2149	.0667	.9793	.6481	1.6550	1.5181	1.8413	1.2022	1.920	1.6151	.2167	.3594	1.1747	.2269
Dominance (DI)	97.9	99.7	92.0	89.5	63.6	72.7	52.2	77.4	84.9	62.9	98.1	97.3	82.3	98.3

(1) Data are the mean of values from the three separate stations (both sets combined).
(2) No sampling during March 1975.

TABLE 3

Percent dry weight of the stomach contents of the bay anchovy, *Anchoa mitchilli*, from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

	SIZE CLASS							
	(20/59) 16–20	(128/173) 21–25	(142/153) 26–30	(87/117) 31–35	(29/54) 36–40	(16/27) 41–45	(15/39) 46–50	(12/21) 51–55*
FOOD ITEM								
Copepod	98	81	67.5	73	59	27	51.5	1
Amphipod		8	22.5	24.5	39.5	0.5	5	3
Crab zoea		6	3.5		0.5	13.5	5	81
Sand	2						1	14
Mollusc		1	1					
Mysid			1.5		1.0			
Polychaete			4					
Algae		1						
Barnacle cypris				1				
Fish (*Lagodon*)						59	37.5	
Nematode								1
Misc.				1.5				
Mud		3						

*July sample only

TABLE 4

Percent dry weight of the stomach contents of the pinfish, *Lagodon rhomboides*, from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

	(37/50)* 11–15	(41/50)* 16–20	(8/13)* 21–30	(6/6) 31–35	(4/5) 36–40	(7/8)** 41–50	(5/5)** 51–60	(3/3)** 61–70
FOOD ITEM								
Copepod	45	21	2	8	1		4	
Oligochaete	32	30	17	5.5	4			
Amphipod	13	22	22	35			5	
Polychaete		13	59		17	31	83	34
Nematode	3	4						
Mysid				34	4			
Fish eggs						5		
Unidentified crustacean					4			
Organic debris	7	10					8	1
Algae				12	70	64		65
Mud				5.5				

*January sample only
**July sample only

TABLE 5

Percent dry weight of stomach contents of the gerreid fishes from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

Species:	*Eucinostomus gula*			*Eucinostomus argenteus*			*Eucinostomus* spp.		
	Size Class			Size Class			Size Class		
	(55/69) 21-40	(119/160) 41-60	(7/10) 21-25	(188/243) 26-45	(12/13) 46-60	(7/9)* 61-80	(7/9) 6-10	(47/63) 16-20	(17/18) 21-25
FOOD ITEM									
Polychaete	69	60	42	32	52	10		18	6
Amphipod	4	12	37.5	7	13	5		2	4
Copepod	3			13			5	39	90
Nematode	6		3.5					15.5	
Oligochaete		8		28	15	85		3	
Mysid	2		3	12					
Barnacle (cirri/cypris)				(also Tanaid)	12		95		
Algae				4					
Mud/sand			14	4	5			13	
Misc.**		2			3			1.5	
Organic debris	16	18						8	

*January

**Misc. - single food items each < 0.5% of total volume (gastropod, nematode, copepod)

O. oglinum proved to be a non-selective benthic grazer with a high proportion of mud and organic debris in the gut. No particular food preference was evident.

The stomachs of the common gobiids examined revealed a wide choice of food items in all the three species. The diversity in diet is best illustrated by the eight categories of items consumed by 11–20 mm *Lophogobius cyprinoides* (Table 7). The *Gobiosoma* species were examined carefully due to the close taxonomic relationship and apparent overlap in key identifying characters (Dawson 1969). The data of the positive identifications (Table 8) proved that a high degree of dietary similarity exists between identical size classes of the two species. Data for the *Gobiosoma* spp. category were based upon fishes identified to genus only and included all data collected for this genus. A high degree of omnivorous behavior and similarity in food selection was evident from the stomach contents of all three gobiids examined (Tables 7 and 8). Sand, mud and detritus formed a significant proportion of the stomach contents in the < 30 mm fishes and suggests a nutritive value, rather than only incidental consumption during feeding. The larger size class fishes appeared more selective in food preference.

Bairdiella chrysura were abundant in the canals during the spring juvenile recruitment period, February through April. Stomachs examined revealed two distinct ontogenetic feeding stages, an early preference for benthic fauna in the < 30 mm fish followed by preference for the most recent anchovy year class (Table 9).

Menidia beryllina was a common resident during the warmer months. Copepods were the major food in the stomachs examined. A significant degree of benthic foraging in the 46–60 mm fish was indicated by the large percentage (48%) of sand/mud observed (Table 9).

TABLE 6

Percent dry weight of the stomach contents for the clupeid fishes from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

	Species:	*Harengula pensacolae*				*Opisthonema oglinum*	
		Size Class				Size Class	
	(31/33) 21–25	(47/47)* 26–30	(33/33)* 31–35	(42/44) 36–40	(70/70)** 41–50	(17/18)** 51–65	(4/4)[I] 26–45	(129/163)[I] 46–75
FOOD ITEM								
Copepod	71	24	79		6	4		
Amphipod	2.5	53						
Crab zoea	1.5	5		55	93	68		
Polychaete		16		6.5		1		
Nematode	13							
Mysid			15					
Misc. III		2		3	1			
Organic debris				35.5			15	26
Algae	9						2[II]	4[II]
Sand	3		6			27		2
Mud							55	68
Detritus							28	

*July only
**July-October
I - September only
II - primarily dinoflagellate
III - Misc. - single food items each < 0.5% of total volume (gastropod, nematode, copepod)

TABLE 7

Percent dry weight of the stomach contents if the crested goby, *Lophogobius cyprinoides*, from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

	Size Class			
	(71/110) 11-20	(31/37) 21-30	(17/20) 31-40	(6/8) 41-50
FOOD ITEM				
Barnacle (cirri/cypris)	8	42		15
Polychaete	2.5	3	3.5	
Mysid	2		6	
Gastropod eggs	7	2.5		
Fish			38*	7**
Copepod	7			
Crab zoea	4	1.5		
Tanaid	3.5			
Amphipod			2	38
Unidentified crustacean		1	1.5	
Organic debris	44	20	48	40
Detritus	22			
Algae			1	
Mud/Sand		30		

*Goby - 1 stomach

**Blenny - 1 stomach

DISCUSSION

The temporal distribution and abundance of the canal ichthyofauna were found to be generally similar to that described for adjacent natural waters (Seaman *et al.* 1973; Yokel 1974; Weinstein *et al.* 1977). Temporal dominance by large numbers of early life stages of only a few species has also been reported in north Florida saltmarshes (Subrahmanyam and Drake 1975). The most numerous fish in this study, *A. mitchilli*, is known to be dominant species in dredged canals along the Gulf Coast (Sykes and Finucane 1967; Trent *et al.* 1972).

Trophic Interactions

Ontogenetic feeding changes were observed in several instances in the Marco Canals. *L. rhomboides* and *B. chrysura* exhibited the clearest examples of these sequential trophic changes. Ontogenetic food selection has been suggested as an important strategy in partitioning of food resources (Darnell 1958; Carr and Adams 1973). Changes in mouth size and swimming ability are key features in trophic selection (Stickney *et al.* 1974). Copepod grazing generally declines as a result of increased efficiency in handling larger prey (Cushing 1975). Therefore, flexibility in food selection could factor as a competitive advantage over species with more strict dietary requirements.

TABLE 8

Percent dry weight of the stomach contents of the gobiid fishes (*Gobiosoma*) from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total number examined.

	Species: *Gobiosoma bosci*					*Gobiosoma robustum*				*Gobiosoma* spp.			
	Size class												
	(5/5)	(8/12)	(9/9)	(9/10)	(1/1)	(4/7)	(35/42)	(16/21)	(2/2)	(39/42)	(213/309)	(67/78)	(2/3)
	11-15	16-20	21-25	26-30	6-10	11-15	16-15	21-25	26-30	6-10	11-20	21-30	31-45
FOOD ITEM													
Copepod	16	25	2			16	6	8		2.5	9	3	
Amphipod		10	34		100	19	14.5			16.5	14	3	45
Barnacle (cirri/cypris)		2	2	18				15	4	6	4	15	
Polychaete		3									5		10
Gastropod eggs		29	17	17				7	21		2	13	
Mollusc													45
Mysid												2	
Unidentified crustacean							1.5			19.5			
Goby eggs			26									1	
Organic debris	59	23	7	65		45	57	51	17	4	52	41	
Mud/sand	25		12			20	18	18	58	51.5	14	22	
Algae		8					3	1					

A high degree of variability in food habits of juvenile pinfish has been described by Hansen (1969) and Odum (1971). Carr and Adams (1973) illustrated a progression in food preference from planktonic and benthic crustaceans (< 30 mm S.L.) to one of vegetation (30–60 mm S.L.) in fish taken from seagrass habitat. The general lack of marine vegetation in the canal would partially explain the observed reduction in abundance of the larger juveniles. Weinstein *et al.* (1977) reported progressive growth of young of the year *L. rhomboides* in seagrass meadows adjacent to the canals until the September offshore migration.

During the winter period of highest dominance within the canals (Table 2), a comparison between the food habits of juvenile *A. mitchilli* and *L. rhomboides* illustrated a partitioning of the available resources. Since these two species move into canals nearly simultaneously, a difference in food preference would serve to reduce competition and more evenly distribute grazing pressure upon the prey species (Keast 1970).

These fishes inhabited the waterways in dense schools throughout the winter period. Bay anchovies remained planktivores and pinfish grazed upon benthic prey. Early benthic feeding stages were common to the majority of the other species examined. However, juveniles of these other species did not appear in abundance until March in a sequence which avoided direct competition with the pinfish. During June, temporarily abundant planktonic crab zoea became a major food source (through August) for the anchovies and *H. pensacolae* which were then codominant in the canal. The cycle of relative abundance within the canal ichthyofauna serves to partition the available forage base.

Data for the gerreids and gobiids illustrate two aspects of competition between closely related species. Competition for scarce resources could force a shift in the forage territories of the competitors result in a spatial stratification which would reduce the degree of interaction (Keast 1970). This may have occurred in the distribution of *E. gula* and *E. argenteus*.

Collections revealed a spatial segregation between the distributions of *E. gula* and *E. argenteus*. *E. gula* demonstrated a preference for the deep trough areas and *E. argenteus* was more abundant along the shallow berm areas (Weinstein *et al.* 1977). A number of investigators have reported the high degree of similarity in the food habits of these two species described in the present study (Odum 1971; Carr and Adams 1973; Brook 1977). Spatial segregation may have served as a mechanism for partitioning available resources and reducing direct interspecific competition.

The proportion of major food items can be partially defined according to the fish's preferred habitat as between the two species of *Eucinostomus*. The instances of overlap in the juvenile food habits were suggestive of an abundant forage base.

The gobies examined are also closely aligned in food preference. In the canal, gobies are concentrated in the seawall oyster community. Courtney (1975) described a diverse macroinvertebrate fauna associated with this habitat. The secretive nature of the gobiid fishes is accommodated by the numerous sheltered crevices of this habitat, and the gobies were routinely taken in large numbers dur-

TABLE 9

Percent dry weight of the stomach contents of the tidewater silverside, *Menidia beryllina*, and the silver perch *Bairdiella chrysura*, from Marco Canals. Figures within parentheses indicate the total stomachs with food over the total examined.

Species:	*Menidia beryllina*[I]			*Bairdiella chrysura*		
	Size Class					
	(21/40)	(35/78)	(14/25)	(67/102)*	(9/14)	(3/4)**
	31-45	46-60	61-65	11-30	31-40	41-50
FOOD INDEX						
Copepod	87	33	96			
Mysid	2					
Amphipod				88	12	
Isopod				9		
Anchovy					66	100
Caridean shrimp					20	
Polychaete				1.5	2	
Insecta		19				
Algae	6					
Sand/mud	5	48	4	1.5		

*February samples only
**April samples only
I - August-October samples

ing rotenone sampling. The omnivorous nature of these species (Tables 7 and 8) revealed a variety of food resources available within the seawall community. Spatial segregation between species was not apparent, in spite of the high degree of overlap in food preferences, due in part to their omnivorous habit and the abundance of available food resources.

ENERGY PATHWAYS

All juvenile fishes examined, with the exception of *O. oglinum*, were primarily carnivorous. Zooplankton were a dominant food item and calanoid copepods were the most abundant of the zooplankters consumed. During the warmer months, planktonic barnacle nauplii and crab zoeal larvae become important foods of the juveniles. Veligers were not identified in any of the stomachs examined, an observation in contrast to the results of Carr and Adams (1973). Weinstein *et al.* (1977) described the canal infauna as poorer in molluscs than adjacent natural habitat.

High winter concentrations of juvenile anchovies are supported by the high winter/spring zooplankton densities observed within South Florida estuarine habitats (Reeve 1975). The presence of large concentrations of the planktivorous life stage of anchovies could reduce the availability of zooplankters for cropping by other species. A decrease in the proportion of copepods consumed by the larger size classes of bay anchovies was reported by Darnell (1958) and Odum (1971). Results of this study confirm an ontogenetic shift from planktonic to benthic and fish trophic resources.

M. beryllina foraged along the benthic and the midwater areas as revealed by

its food habits (Table 9). A diurnal feeding cycle has been described for atherinids (including *M. beryllina*) involving nightly benthic and daily pelagic foraging (Odum 1971; Brook 1977). The timing of the midmorning seine collections would explain the observed mix of both benthic and pelagic prey.

H. pensacolae, a primary planktivore, exhibited a wide range in food preference (Table 6). The dominance of crab zoea (*Petrolisthes* spp.) in *H. pensacolae* stomach contents was due to a brief abundance of these larvae in the canal. Carr and Adams (1973) observed a similar case of opportunism in Crystal River fish.

Several examples of fish predation are noted in these data, however, *B. chrysura* is the only species which can be described as a piscivore. A large mouthgape enable young *B. chrysura* to capture and consume anchovies of their own size range.

Detritus based food chains are considered the prime energy pathway in estuarine systems (Odum and De La Cruz 1967; Odum *et al.* 1973). In the canal only *O. oglinum* consumed detritus to any major degree. This species was revealed as a non-selective feeder due to the high proportion of mud, detritus and organic debris observed (Table 6). *O. oglinum* has been described as a general planktivore (Fuss *et al.* 1968). Odum (1968) suggested that a long digestive tract, such as is found in *O. oglinum*, would permit the utilization of the bacterial flora of detrital particles.

Benthic copepods and amphipods are also known to actively consume detritus and have been suggested as the key link in the passage of energy from this source to higher trophic levels (Odum *et al.* 1973; Silbert *et al.* 1977). Pelagic estuarine copepods have also been found capable of utilizing suspended detrital particles (Lenz 1977), providing a detrital input to planktonic consumers.

Generally higher chlorophyll values have been recorded in Marco canals than in adjacent natural waters, suggesting a phytoplankton-based food chain within the canal (Weinstein *et al.* 1977). While phytoplankton did not appear as major food items within the juvenile fish diets, the predation upon calaniod copepods would be an indirect autotrophic subsidy for the canal fishes. Quasim (1970) noted that tropical estuarine systems were usually heavily cross-linked and up to 80 percent of the autotrophic production would be consumed *in situ* by pelagic zooplankters. The presence of benthic harpacticoid copepods in the juvenile stomachs and the reports of Lenz (1977) and Heinle *et al.* (1977) suggest that energy may also be derived from detrital decomposition.

Other common food items included crustaceans (amphipods, isopods and shrimps) and benthic infauna (primarily polychaete worms). Intentional herbivorous grazing is not a major energy pathway in estuarine fishes (Darnell 1961; Adams *et al.* 1973). In the canals only pinfish were found to consume attached plant material.

In summary, the most abundant juvenile fishes of the Marco canals are predominantly pelagic feeders with copepods and planktonic life stages of macrocrustaceans constituting the major food items in the smallest size ranges exam-

ined. Benthic crustaceans and polychaetes become more important trophically as the juveniles increased in size.

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NEREIS (NEANTHES) MICROMMA N. SP. (POLYCHAETA: NEREIDIDAE) FROM THE NORTHERN GULF OF MEXICO WITH A NOTE ON THE STRUCTURE OF NEREIDID PALPS

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ABSTRACT

A new species of polychaete annelid, *Nereis (Neanthes)* micromma, is described and illustrated. The species, which is most abundant on muddy sand bottoms, has been collected offshore from the Texas and Louisiana coasts in the northern Gulf of Mexico; it has also been collected in Gulf influenced bay areas in Texas. Although present the entire year in Texas waters, population data indicate maximum reproductive activity occurs in the fall. Most specimens have been collected from waters of 25 to 36 parts per thousand salinity.

The inappropriateness of "biarticulate" in describing the palps of some nereidids is discussed.

INTRODUCTION

Numerous specimens of a nereidid* polychaete that could not be assigned to any known species were collected during several successive research projects conducted off the Texas coast beginning in 1973. The species, described herein, was consistently called *Nereis* sp. in all project reports (Harper and Case 1975; Harper, Scrudato and Giam 1976; Harper 1977a, b). The species has also recently been collected at several localities offshore from the Louisiana coast west of the Mississippi Delta (unpublished data).

The genus *Nereis* is separated into two subgenera, *Nereis (Nereis)* which has homogomph falcigers in the posterior notopodia, and *Nereis* (*Neanthes*) which lacks them. The new species belongs in the latter subgenus. Many authors, including Fauchald (1977), consider the differences in posterior setae sufficient to elevate the subgenera to generic status.

Specimens of *Nereis micromma* have been deposited in the following collections: National Museum of Natural History, Washington, D.C. (USNM), Texas A&M Marine Laboratory, Galveston, Texas (AMML), working collection, Department of Oceanography, Texas A&M University, College Station, Texas

* The orthographic familial spelling is Nereididae (Pettibone, personal communication), thus the common term is nereidid. Whether this usage will be widely accepted remains to be seen.

(TAMU); Allan Hancock Foundation, University of Southern California, Los Angeles, California (AHF).

NEREIS (NEANTHES) MICROMMA SP. NOV.

Material examined—TEXAS: Freeport, 19 km offshore on muddy sand bottom of drowned Brazos-Colorado River delta, 28°44.5′N, 95°13.2′W, 21 m, 2 December 1977, holotype (USNM 55575), 17 paratypes (USNM 55576, 55578), 12 paratypes (AHF Poly 1251), 5 paratypes (AMML); 4 January 1978, 10 specimens (AMML), 4 specimens (TAMU); 24 February 1978, 3 specimens (AMML). Freeport, 8 km offshore on clay bottom of Brazos River subaqueous delta, 28°49.4′N, 95°19.6′W, 17 m, 15 December 1977, 1 specimen (USNM 55577), 8 specimens (TAMU). Freeport, 15 km offshore on muddy sand bottom, 28°44.3′N, 95°17.5′W, 21 m, 29 May 1973, 6 specimens (USNM 55691). Galveston, muddy sand bottom of U.S. Army Corps of Engineers spoil disposal area off Galveston, 29°17.0′N, 94°41.1′W, 10 m, 23 January 1976, 8 specimens (USNM 55579); 24 January 1976, 1 specimen (AMML). Buccaneer Oil/Gas Field, about 50 km south of Galveston, 28°53.3′N, 94°41.5′W, sand-mud bottom, 21 m, 13 specimens (USNM 55580), 6 specimens, (AMML).

Other records—TEXAS: Lower Matagorda Bay, sandy mud bottom, 4 m. LOUISIANA: offshore from Atchafalaya Bay to Mississippi Delta in depths of 9 to 45 m.

Diagnosis: Body slender, elongate; prostomium with 2 pairs of small eyes, pair of short antennae and pair of palps; peristomium with 4 pairs of tentacular cirri, the upper posterior pair twice as long as others; proboscis with few paragnaths on areas IV, VI and VII–VIII; upper notopodial ligule first appears on setiger 6; in posterior segments, upper notopodial ligule enlarged, foliaceous, vascularized, with small terminal dorsal cirrus; notoacicula lacking in far posterior parapodia.

Description: Body long; cylindrical anteriorly, somewhat dorsoventrally flattened and tapering posteriorly. Prostomium (Fig. 1a) with 2 short tapered antennae, 2 tapered palps, the distal halves of which mostly retract into proximal halves (creating appearance of biarticulate palps), and 2 pairs of small eyes; anterior pair slightly arcuate, posterior pair suboval. Peristomium (Fig. 1a) with 4 pairs of tentacular cirri; anterior pairs and ventral posterior pair subequal, reaching to setiger 1 or 2; posterior pair twice as long, reaching setiger 3 to 7 depending on state of state of contraction of anterior segments. Proboscis (Figs. 1b, c) with pair of toothed jaws and very few conical paragnaths; dental formula —area I: 0; area II: 0; area III: 0; area IV: 0–3 in oblique row; area V: 0; area VI: 0–5 in triangle, arch or row; area VII–VIII: 3–5 in single row (occasionally in pairs).

First and second segments following peristomium subbiramous, having dorsal cirrus, lower notopodial ligule, neuropodial postsetal lobe and ventral cirrus; upper notopodial ligule, notosetae and notoaciculum lacking (Fig. 2). Remaining parapodia biramous. Parapodia 3 through 5 similar, with dorsal cirrus, lower notopodial ligule, postsetal lobe and ventral cirrus (Fig. 3). Upper notopodial

ligule of larger adults appearing first on setiger 6 (Fig. 4) and present thereafter. On smaller adults the upper notopodial ligule first appears on setiger 7, and on young specimens, 25–35. Upper notopodial ligule smaller than dorsal cirrus on setiger 6, slightly smaller on setigers 7 and 8 and subequal or slightly larger to about setiger 20 (Fig. 5). From setiger 20 to about setiger 50, upper notopodial ligule smaller than dorsal cirrus, and smaller, more cirriform than subtriangular lower notopodial ligule. Neuropodial ligule and ventral cirrus subequal.

Upper notopodial ligule begins enlarging at about setiger 50, becoming noticeably larger and triangular by setiger 60. In middle and posterior body regions, upper ligule enlarged, foliaceous and vascularized, with small terminal dorsal cirrus (Fig. 6).

Setae located as follows: notosetae, where present, in a line slanting downward and posteriorly above lower notopodial ligule; upper neurosetae in bundle immediately above and behind acicular lobe; lower neurosetae in semicircle below and behind acicular lobe, almost contiguous with upper notosetal bundle. Shafts of all setae canaliculated. Spiniger blades range from long to short within setal bundles and from parapodium to parapodium; from setiger 3, short bladed spinigers consistently occur in upper neuropodial bundle, anterior part, and lower neuropodial semicircle, below acicular lobe.

On setiger 1, upper neurosetal bundle consisting of anterior heterogomph falcigers with rounded tips and coarse teeth (Fig. 7a) and posterior homogomph spinigers (Figs. 7b, c, d). Lower neurosetae are all heterogomph falcigers with rounded tips and coarse teeth (Fig. 7e). On setiger 2, upper neurosetae are short bladed heterogomph spinigers in anterior part of bundle (Fig. 8a) and homogomph spinigers posteriorly (as in Figs. 7b, c, d); lower neurosetae are heterogomph falcigers with fine teeth below acicular lobe (Fig. 8b) and heterogomph spinigers behind lobe (Fig. 8c).

On remaining anterior segments, notosetae are homogomph spinigers; upper neurosetae are anterior short bladed heterogomph spinigers (Fig. 8a) and posterior homogomph spinigers (Figs. 7b, c, d); lower neurosetae are short bladed heterogomph spinigers (Fig. 8a) below acicular lobe and longer bladed heterogomph spinigers behind lobe.

Setae become less numerous posteriorly; separation between upper and lower neurosetal bundles less distinct. Notosetae in posterior body region are 2–3 homogomph spinigers (Fig. 9a), upper neurosetae are 2 heterogomph spinigers (Fig. 9b) and 2–3 longer bladed homogomph spinigers; lower neurosetae are 2 heterogomph falcigers (Fig. 9c) and 2 short bladed heterogomph spinigers (Fig. 8a). Far posterior parapodia lacking notoacicula; notopodium represented by ligule and single homogomph spiniger. Neurosetae are as on preceding posterior segments. Pygidium bilobed with pair of anal cirri (Fig. 10).

Etymology: The specific epithet refers to the small eyes of the species.

Size range: The holotype, an adult worm 86 mm long, 1.0 mm wide and having 240 fully formed segments followed by 12 incompletely developed segments, is the largest complete specimen collected. A headless specimen (USNM 55577), broken between setigers 5 and 6, is 98 mm long, 1.5 mm wide and has 300 fully

formed segments, followed by 12 incompletely formed segments. Thus adult specimens attain lengths of 100 mm or more.

Color: When living, anterior segments colorless, semi-transparent, and jaws may be seen through integument. Golden flecks appear in dorsal integument by setiger 17, becoming more abundant posteriorly; dorsal surface and upper notopodial ligules almost completely golden in middle and posterior segments. Blood red; dorsal vessel narrow anteriorly, becoming broader posteriorly, easily seen through transparent ventral surface. Jaws amber; acicula black; setae dark.

When preserved, the body is uniformly opaque white with no hint of the beauty of the living worm. In rose Bengal stain, structures in the ligules absorb much stain, turning bright red while remainder of body stains light pink. Under magnification, bright red areas appear glandular, consisting of highly convoluted tubular structures giving rise to slender tubular structures running toward tip and base of ligule. These stained structures present in lower notopodial and neuropodial ligules from setiger 1; in former, mass fills most of ligule, and in latter, mass occupies ventral half of ligule and may extend into parapodium proper. Structure present in upper notopodial ligule from setiger 6; in cirriform ligule, structure cylindrical, filling much of ligule; in foliaceous, mid-body ligules, structure restricted to tip of ligule, and is absent from far posterior ligules.

Distribution: The species is presently known only from the northern Gulf of Mexico, having been collected from the upper Texas coast and the Louisiana coast. The species occurs from near Gulf bay bottoms to about 45-m depth offshore.

Notes on living worms: Living worms, collected on 23 February 1978 off Freeport, Texas in 21-m depth, were observed in the laboratory. In a finger bowl with no substrate, the anterior end of the worm was active, but the posterior end was usually kept coiled. The specimens exhibited no tendency to swim, but thrashed violently if touched. If a substrate was provided, the worms immediately began to burrow, using the proboscis to create a path through the sediment. Burrowing was accomplished rapidly.

The ventrally directed palps were kept extended and relatively close together (Fig. 11), unlike the preserved state in which the palps almost always curve outward and the distal halves are mostly retracted into the proximal halves (Fig. 1a). The palps constantly probed the bottom of the container and were periodically retracted and reextended.

The tentacular cirri were carried as follows: anterior dorsal—forward about 45° and extended laterally; anterior ventral—forward about 45° and extended ventral (usually in contact with the bottom of the container); posterior dorsal —forward about 30–45° and extended dorsally about 30° from the vertical; posterior ventral—perpendicular to the side of the body.

The living worms were broadest at setiger 6 or 7. Peristomium and segments 5–8 with lateral and ventral longitudinal ridges.

Ecological notes: *Nereis micromma* was collected most frequently from muddy sand bottoms, occurring infrequently on silt or clay bottoms, and has not been

collected from hard sand bottoms. Most specimens have been collected from localities having bottom water salinities of 25 to 36 parts per thousand.

The population trends of *N. micromma* at two study areas, 8 and 19 km off Freeport, Texas, are shown in Figure 12. Sediment temperature and bottom water salinity trends in the two study areas are provided for comparison (Fig. 13). The worms were more abundant on muddy sand bottoms at the 19 km site (21-m depth) than on the predominantly clay bottoms at the 8 km site (17-m depth). Populations were largest in the fall (October–December) and smallest in late spring (May–June), and were larger in the 1978–79 fall–winter period than during the same period in 1977–78. The presence of heteronereidids in the June through August samples, followed immediately by a population irruption in September–October, indicates that spawning occurred primarily in the early fall, triggered by decreasing temperatures. Of particular interest is the population trend between December and April at the 19 km site; the populations declined to a low in February, underwent an increase in March, and declined again in April. When this pattern emerged in 1977–78, it was thought to be due to sampling error, but reoccurrence in 1978–79 indicates that it may be an annual event. A similar trend occurred at the 8 km site, but is not as distinct because of the smaller population size. In both instances, the depressed populations coincided with the lowest recorded sediment temperatures and the March increases occurred as the temperature began to increase. The salinity was relatively stable throughout the study at the 19 km site and probably had little, if any, influence on the trends. Because there was no indication of a brief reproductive period preceding the March population increase, the short-lived population decrease in the middle of winter may have been caused by the worms burrowing deeper into the substrate than the sampling devices (15 cm high Ekman grabs) could penetrate, thus avoiding the cold temperatures of the upper sediment layers.

During this period of study, *Nereis micromma* was the third most abundant benthic species at the offshore site, comprising 6% of the population, and was eighth in abundance on the nearshore clay bottoms, comprising 2% of the population.

Similar species: Of the several species of nereidids that coexist with *Nereis micromma*, only one, *Nereis (Neanthes) succinea* Frey and Leuckart, 1847, is similar. The posterior parapodia of both species have enlarged, foliaceous upper notopodial ligules with small, terminal dorsal cirri. The latter species can be easily separated by the larger eyes, the dark brown dorsal color on the anterior part of the body and the larger, more numerous paragnaths.

A NOTE ON THE STRUCTURE OF NEREIDID PALPS

Most authors include "biarticulate palps" as a characteristic of the Family Nereididae; the palps of most nereidids examined do appear to have a thick basal segment and a smaller, button-like terminal segment. *Nereis micromma* is no exception, and it was not until a number of specimens with extended palps were

collected that the characteristic was questioned. Examination of living *N. micromma* confirmed that the palps are, in fact, eversible, much the same as the proboscis. If preserved specimens are carefully examined using transmitted light, the separation line between the basal and distal parts of the palp may be seen.

Living *Nereis succinea* were collected from an oyster reef in West Bay, Galveston, and examined also. The palps were eversible as in *N. micromma*. When probing the bottom of the container, the palps inverted and everted. When *N. succinea* is preserved, however, the palps appear biarticulate and the line between the basal and distal parts is obscured by head coloration.

Because two species of *Nereis* (*Neanthes*) have eversible rather than biarticulate palps, it is probable that many, if not all, members of the genus share the trait, and that eversible palps may be common to the family. If so, the family will require a slight redefinition.

ACKNOWLEDGMENTS

I thank Dr. Marian Pettibone of the Smithsonian Institute for confirming the new species. Dr. Pettibone, Nancy Rabalais, University of Texas Marine Science Institute, Port Aransas and Nancy Maciolek, Woods Hole Oceanographic Institution, reviewed the manuscript, making many helpful suggestions. I also thank my associates, particularly Robert Salzer, Rebecca Jaschek, Deborah Potts, Clyde Henry and Larry McKinney, for their assistance in collecting and sorting the benthic samples containing the new species. This research was supported by U.S. Army Corps of Engineers Contract DOA Res DACW-64-75-C-0070, National Marine Fisheries Service Contract 03-6-042-35117, Department of Commerce Grant 04-6-158-44108, and Bureau of Land Management Contract AA 551-CT8-17, Ecological Investigations of Petroleum Producing Platforms in the Central Gulf of Mexico, administered through the Southwest Research Institute, Houston, Texas.

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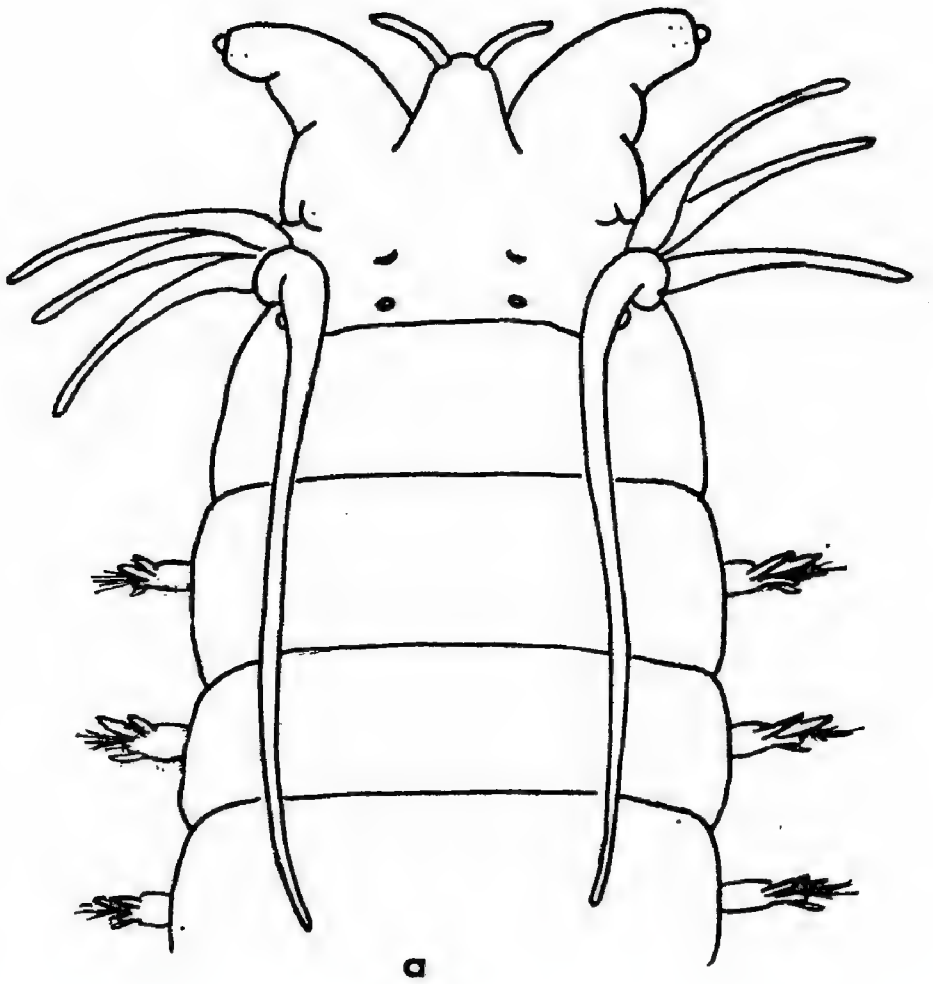

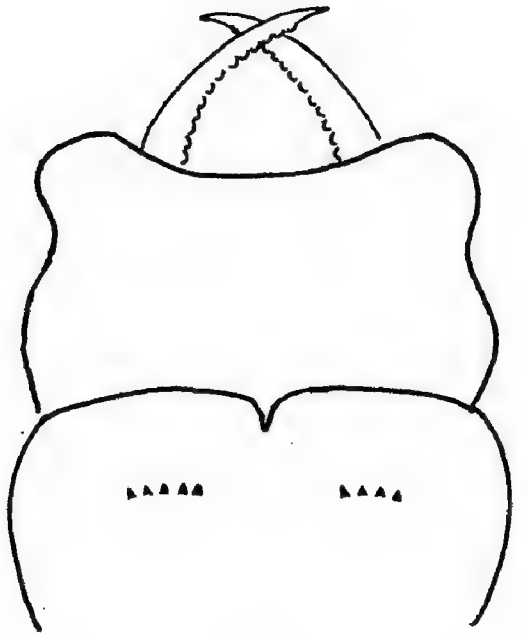

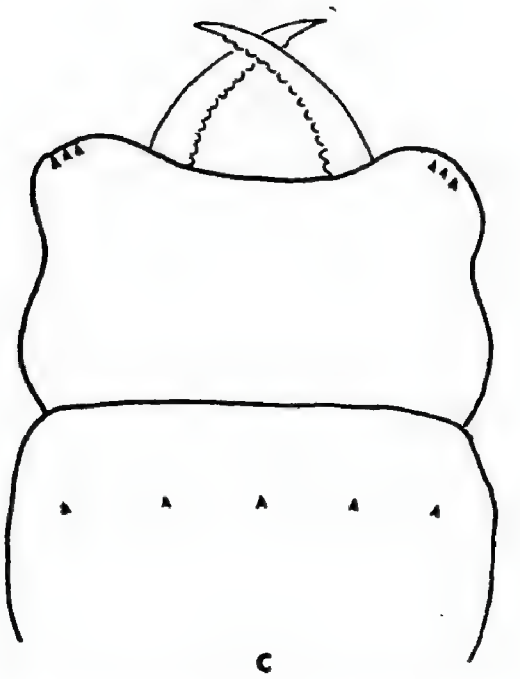

FIG. 1. *Nereis (Neanthes) micromma* n. sp. a) anterior end, dorsal view of preserved worm; b) dorsal view of extended proboscis; c) ventral view of extended proboscis.

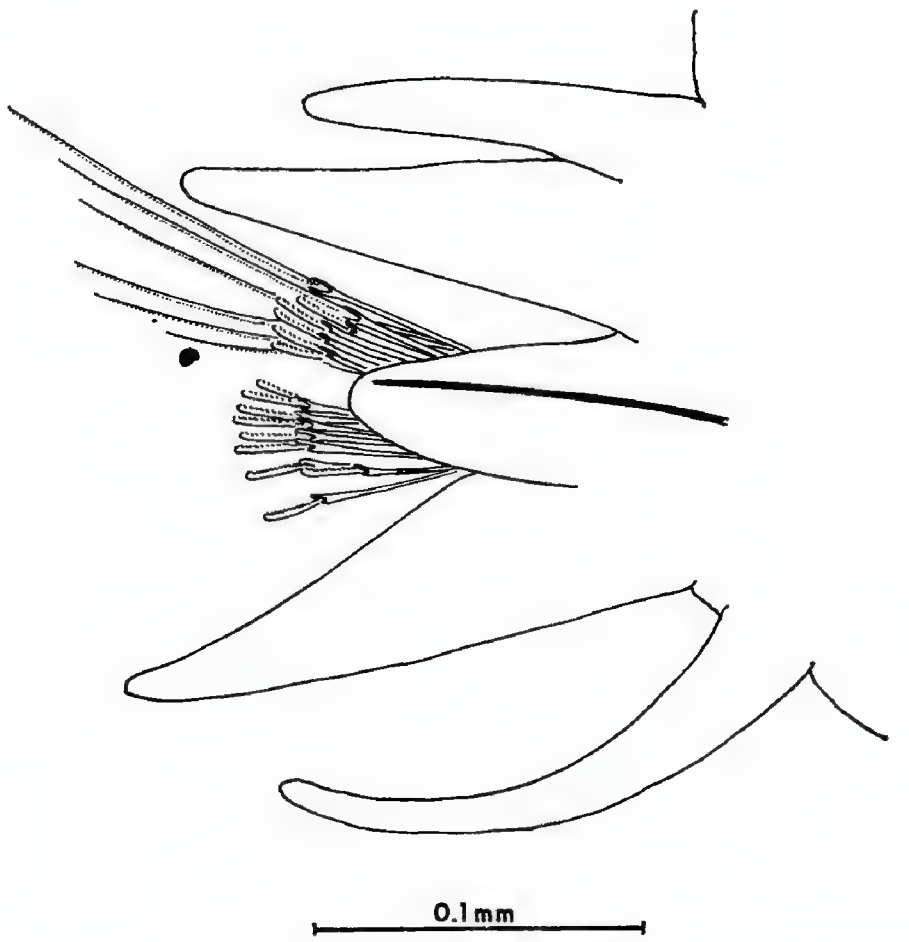

FIG. 2. *Nereis (Neanthes) micromma* n. sp. Right 1st parapodium, anterior view.

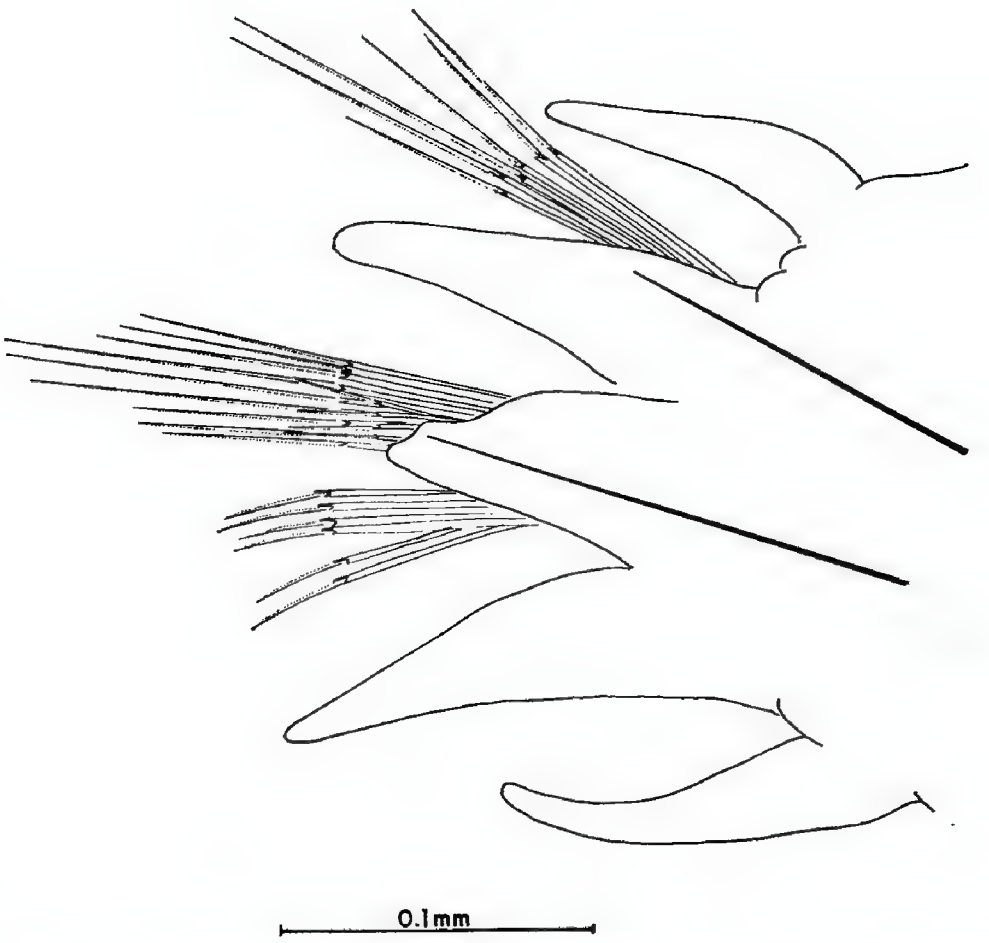

FIG. 3. *Nereis (Neanthes) micromma* n. sp. Right 5th parapodium, anterior view.

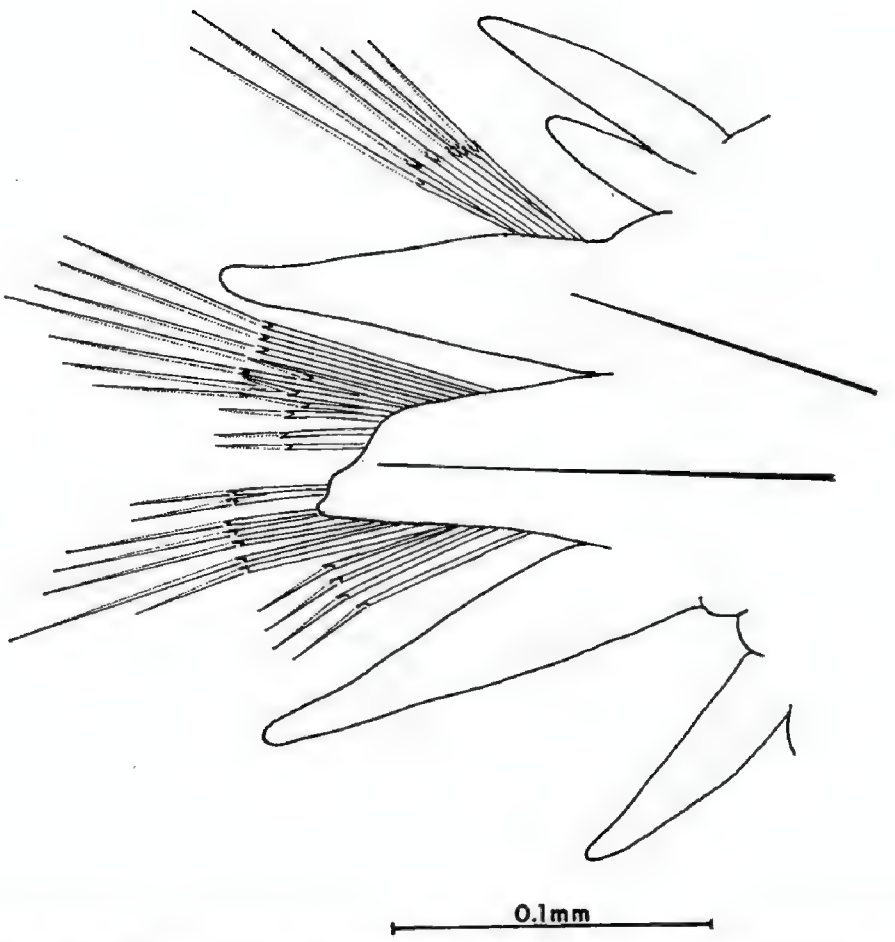

FIG. 4. *Nereis (Neanthes) micromma* n. sp. Right 6th parapodium, anterior view.

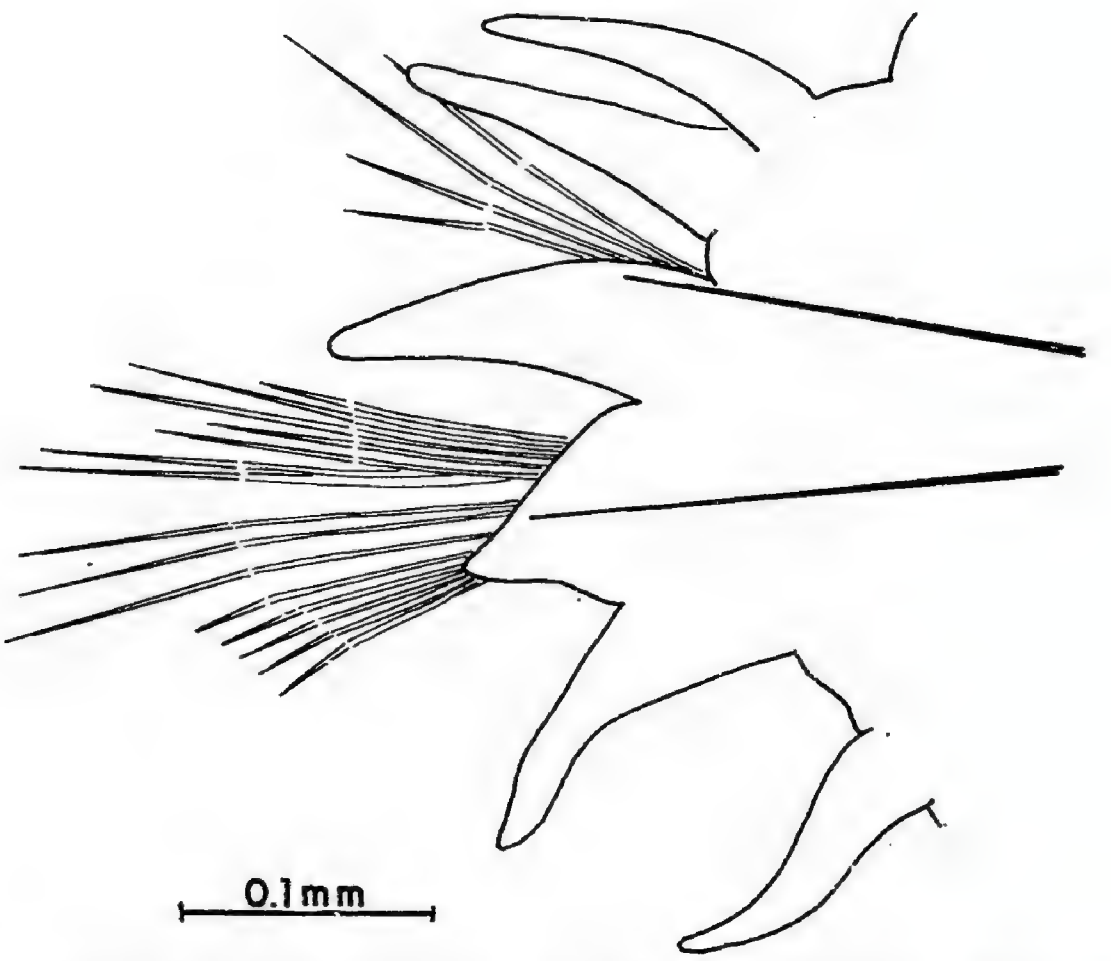

FIG. 5. *Nereis (Neanthes) micromma* n. sp. Right 15th parapodium, anterior view.

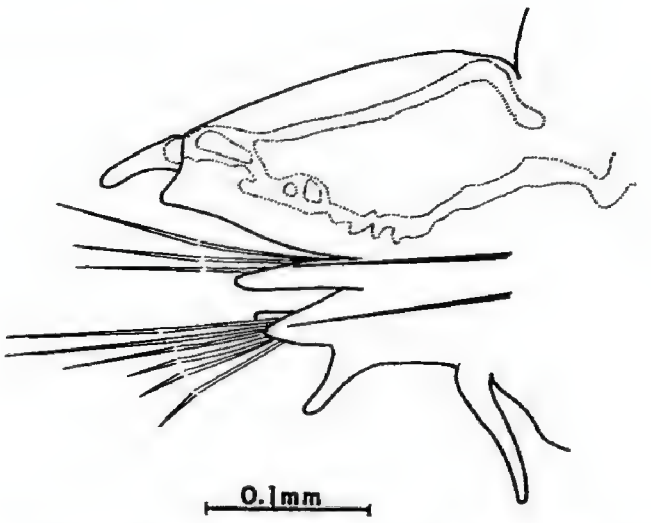

FIG. 6. *Nereis (Neanthes) micromma* n. sp. Right 150th parapodium, anterior view.

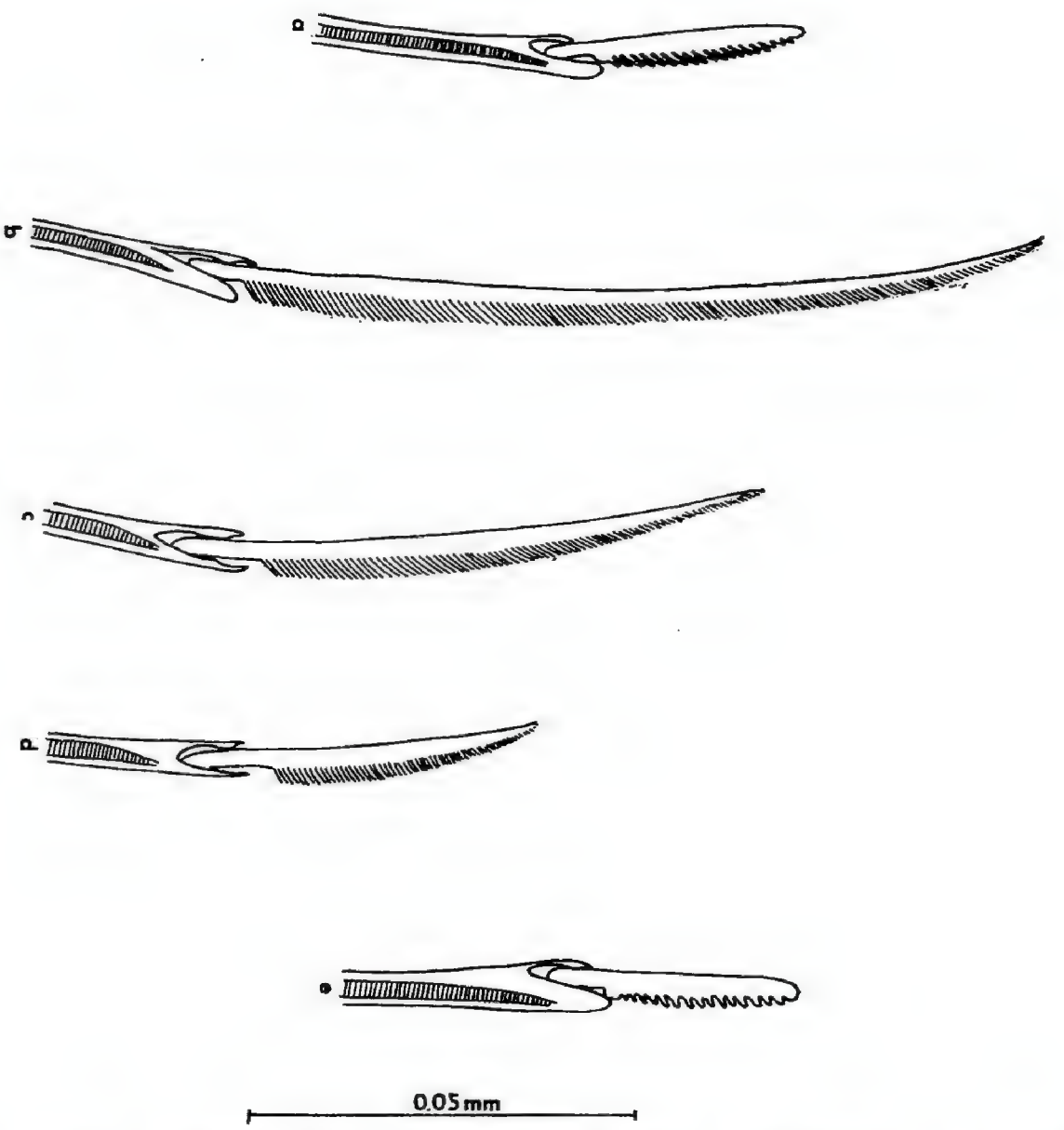

FIG. 7. *Nereis (Neanthes) micromma* n. sp. Neurosetae from setiger 1: a) upper anterior heterogomph falciger; b) upper posterior long bladed homogomph spiniger; c) upper posterior medium bladed homogomph spiniger; d) upper posterior short bladed homogomph spiniger; e) lower heterogomph falciger.

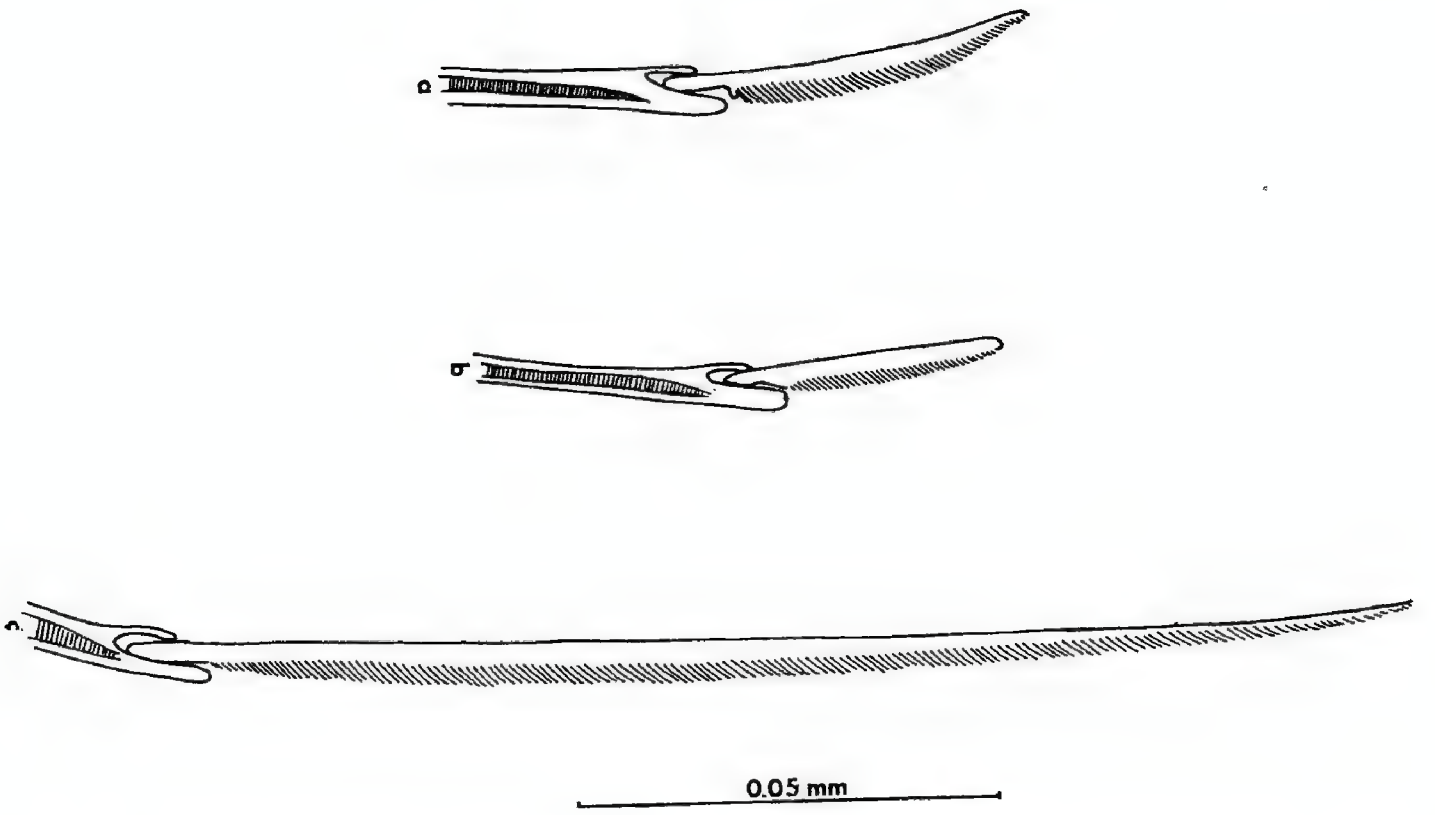

FIG. 8. *Nereis (Neanthes) micromma* n. sp. Neurosetae from setiger 2: upper anterior short bladed heterogomph spiniger; b) lower heterogomph falciger; c) lower heterogomph spiniger.

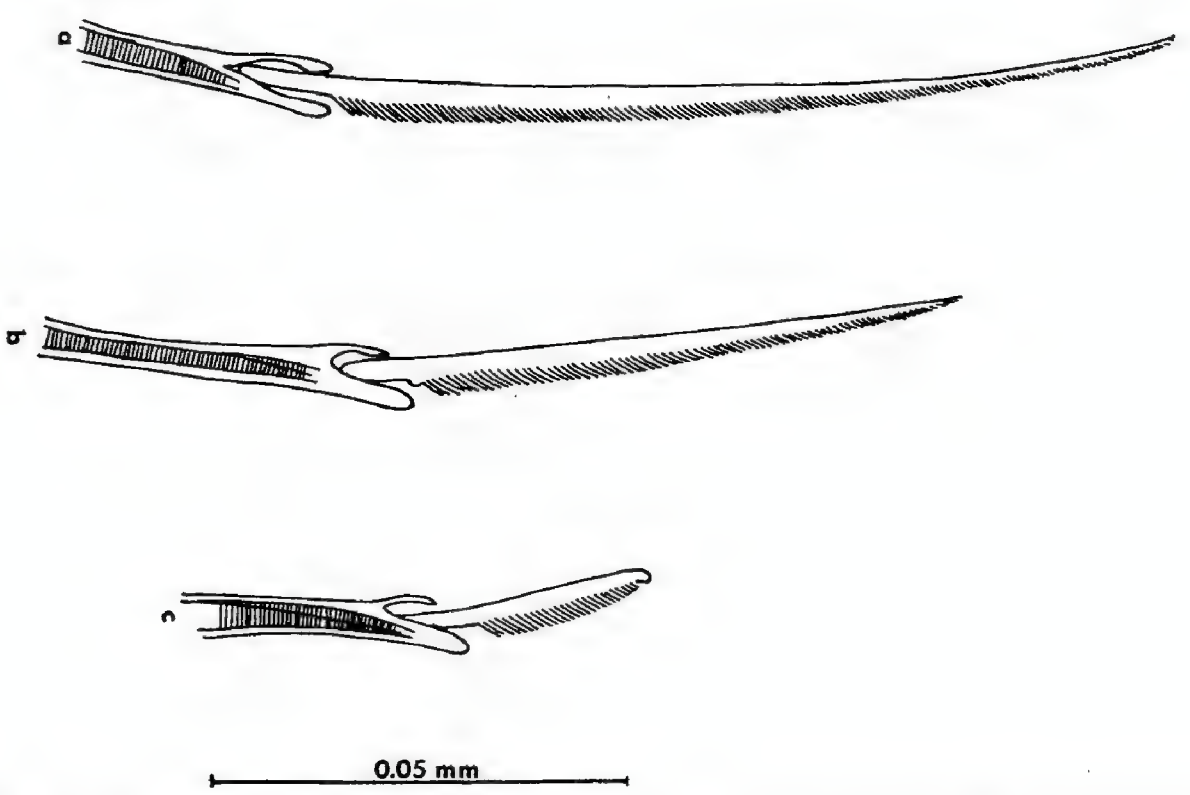

FIG. 9. *Nereis (Neanthes) micromma* n. sp. Setae from parapodium 150: a) notopodial homogomph spiniger; b) upper neuropodial heterogomph spiniger; c) lower neuropodial heterogomph falciger.

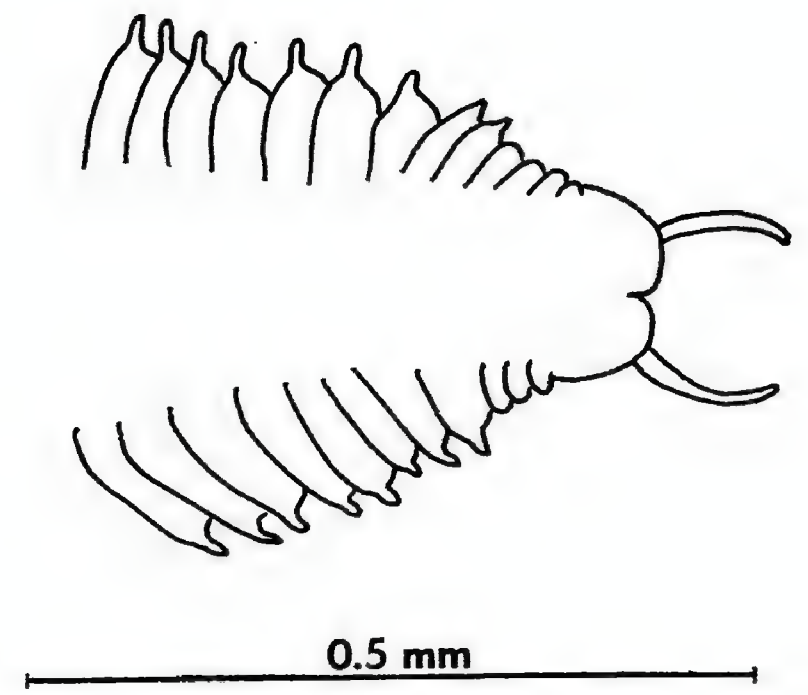

FIG. 10. *Nereis (Neanthes) micromma* n. sp. Posterior end and pygidium, dorsal view.

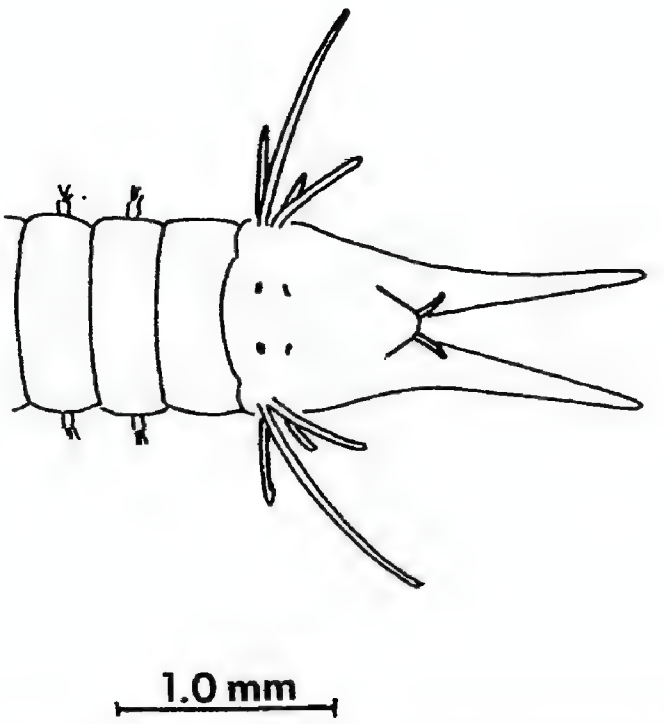

FIG. 11. *Nereis (Neanthes) micromma* n. sp. Dorsal view of living worm showing the approximate attitude of palps and tentacular cirri.

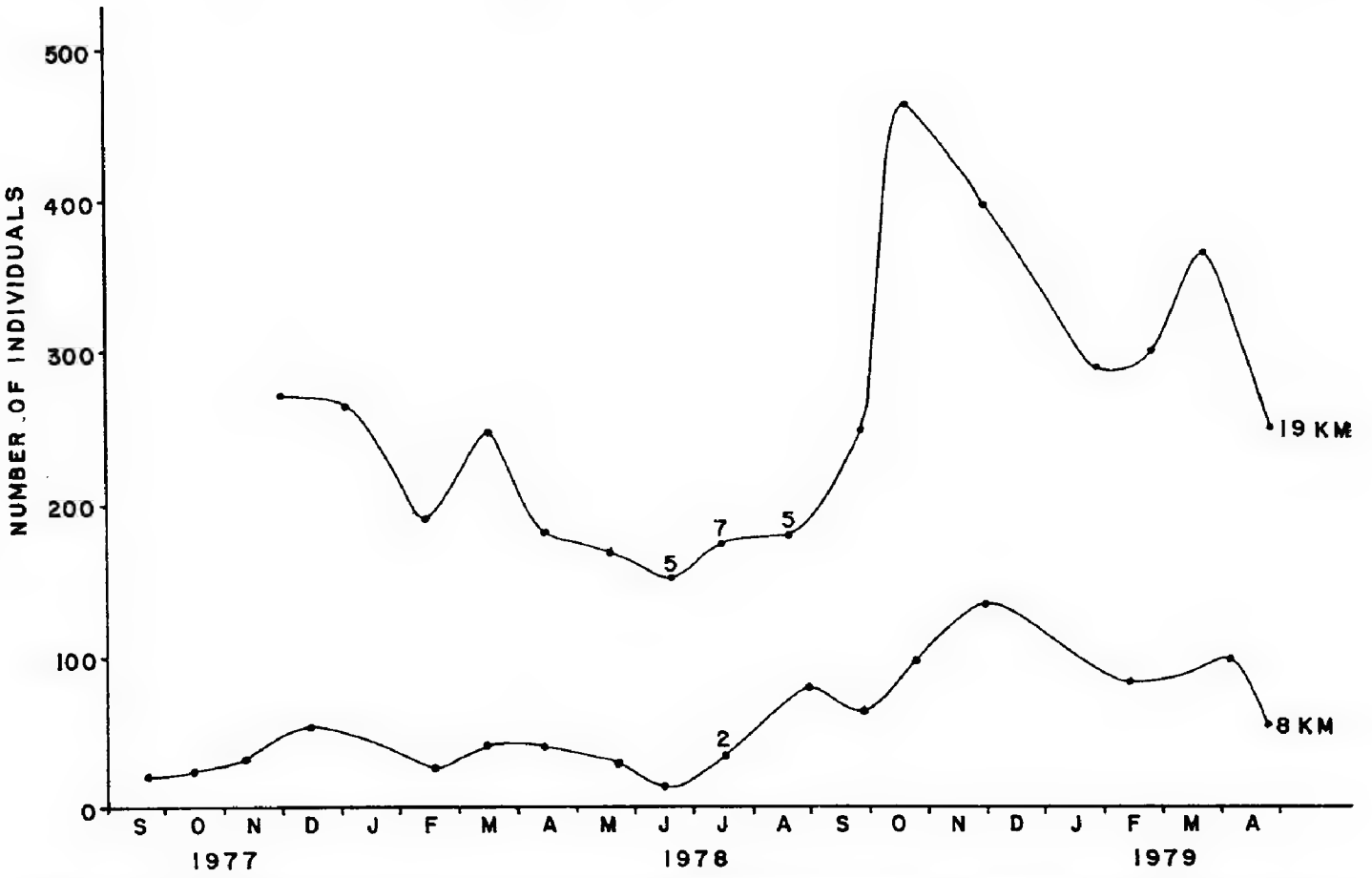

FIG. 12. Temporal trends in abundance of *Nereis micromma* at two study areas, 8 km (17-m depth, clay bottom) and 19 km (21-m depth, muddy sand bottom), off Freeport, Texas. Data points are the total number of individuals collected at the 15 stations in each study area. Numbers above data points represent total number of heteronereidids collected.

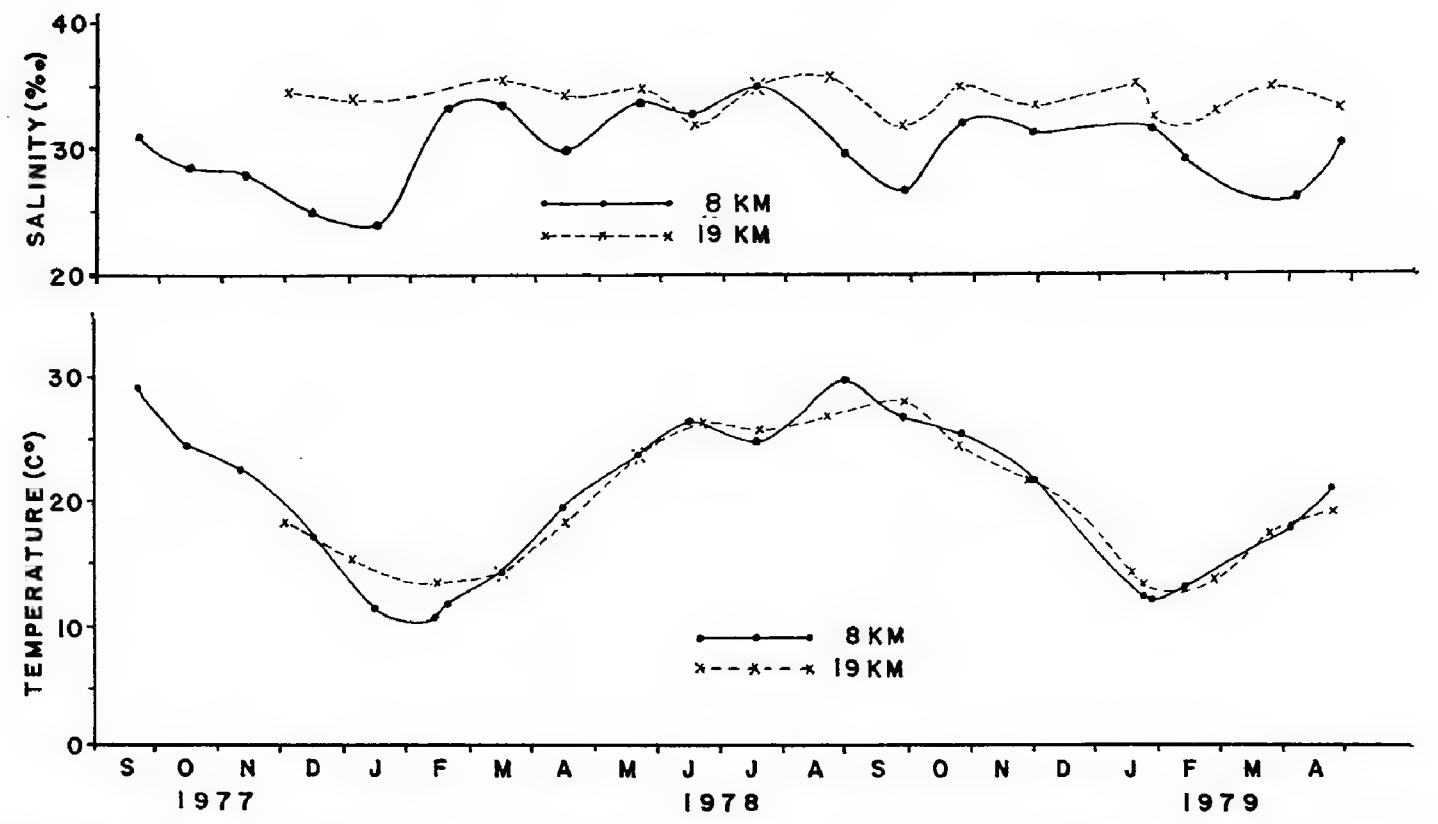

FIG. 13. Temporal trends in the sediment tempreature and bottom water salinity at two study areas, 8 km (17-m depth, clay bottom) and 19 km (21-m depth, muddy sand bottom), off Freeport, Texas. Data points are the average temperature and salinity recorded during each cruise. The several abiotic data points without corresponding *Nereis* population data points represent cruises aborted before all stations were occupied; abiotic data were used while biological data were not.

THE GENUS *POLYSIPHONIA* (CERAMIALES, RHODOPHYTA) IN THE VICINITY OF PORT ARANSAS, TEXAS

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Contribution No. 896 to the UNC-W Marine Service Program

ABSTRACT

Illustrations, descriptions, and taxonomic notes are provided for nine species of *Polysiphonia* occurring in the vicinity of Port Aransas, Texas. Two of the species, *P. macrocarpa* and *P. flaccidissima*, are newly reported for the area. Comparisons are made with descriptions for these species elsewhere, and taxonomic and phytogeographic conclusions given.

INTRODUCTION

In the genus *Polysiphonia* Greville, speciation is based on morphological features including the position of trichoblasts and scar cells, origin of branches, nature of antheridial branches and cystocarps, arrangement of tetrasporangia, and origin of rhizoids (Hollenberg 1942; Segi 1951). These critical taxonomic features have been described and illustrated in monographic treatments for species in the Indo-Pacific (Hollenberg 1968a, 1968b; Meñez 1964; Rao 1967; Segi 1951; Tseng 1944), Pacific coast of North America (Hollenberg 1942, 1944, 1961), Gulf of California (Hollenberg and Norris 1977), western Mediterranean (Lauret 1967, 1970) and coastal North Carolina (Kapraun 1977).

Although several publications have treated the ecology and life histories of the *Polysiphonia* species on the Texas coast of the Gulf of Mexico (Edwards 1968, 1969, 1970a, 1970b; Edwards and Kapraun 1973), and one species described from the region (Wynne and Edwards 1970), critical studies of taxonomic features have not been done for most of the species reported from the region. While considerable morphological variation has been shown to exist within given taxa of *Polysiphonia* elsewhere (Kapraun 1977, 1978a, 1978b), the extent of morphological variability in Texas species remains unknown. Consequently, the present study was undertaken to provide critical illustrations and descriptions for Texas coast of Gulf of Mexico taxa.

MATERIALS AND METHODS

Illustrations and descriptions of the *Polysiphonia* species are based on specimens collected during June and July, 1978, from habitats in Aransas and Redfish Bays, and the jetties at Port Aransas as described by Edwards (1970b). *Polysiphonia tepida* was not encountered during this

study, so herbarium specimens (TEX) were studied of plants collected by the author and Dr. Edwards during the summer of 1968 at Port Aransas. Voucher specimens and microscopic slides for this study are deposited in the Herbarium of UNC-Wilmington (WNC).

Key to the species of Polysiphonia in the vicinity of Port Aransas, Texas

1. Pericentral cells 4 2
1. Pericentral cell 5 or more 7
   2. Branches arising in the axils of trichoblasts 3
   2. Branches replacing trichoblasts 6
3. Rhizoids in open connection with pericentral cells ..... *P. havanesis*
3. Rhizoids cut off from pericentral cells 4
   4. Plants minute, to 1 cm tall from an extensive creeping base ..... *P. flaccidissima*
   4. Plants larger, more than 1 cm tall from a discoidal base 5
5. Plants less than 3 cm tall, epiphytic on *Halodule wrightii*; tetrasporangia little swollen in long series ..... *P. gorgoniae*
5. Plants to 6 cm tall; main axes beset with spine-like branches; tetrasporangia nodose in short branchlets ..... *P. echinata*
   6. Plants minute, to 1 cm tall, and delicate with main axes less than 80 μm diam; branches developing unilaterally from prostrate axes, giving plants a dorsiventral habit ..... *P. macrocarpa*
   6. Plants to 3 cm tall, main axes to 150 μm diam; branches developing radially from both prostrate and erect axes ..... *P. subtilissima*
7. Branches arising in axils of trichoblasts 8
7. Branches replacing trichoblasts; pericentral cells 6 (—7) ..... *P. boldii*
   8. Pericentral cells 6 (—5); plants essentially erect to 6 cm tall ..... *P. denudata*
   8. Pericentral cells 8 (—7); plants with an extensive creeping system; erect axes to 2 cm tall ..... *P. tepida*

Polysiphonia havanensis Montagne *sensu* Børgesen (Figs. 1–3)

Plants reddish-brown, with an extensive creeping system giving rise to erect filaments, 2–4 cm tall; main axes to 80 μm diam, alternately branched and with an abundance of adventitious branchlets arising from persistent scar cells; pericentral cells 4; apices with numerous, highly branched trichoblasts; basally attentuated branches arising in the axils of trichoblasts; prostrate axes to 100 μm diam, giving rise to rhizoids from the middle of pericentral cells to which they remain in open connection; spermatangial branches cylindrical, 50–60 × 250–300 μm, lacking sterile tip cells, clustered in spirals in branch tips; pericarps broadly oval, 250–300 μm; tetrasporangia to 60 μm diam, slightly swollen in long spiral series in branch tips.

The taxonomic validity of this species is in question (Ardre 1970; Kapraun 1977), but the familiar epithet is retained here until a critical determination can be made.

Distribution: Polysiphonia echinata is reported in the northern Gulf of Mexico American tropics (Taylor 1960) and the Gulf of Mexico (Edwards and Kapraun 1973; Dawes 1974.)

Specimens studied: DK-*s.n.* male, cystocarpic tetrasporic, sublittoral on breakwater, Fulton Harbor, 20 June 1978.

Polysiphonia echinata Harvey (Figs 4–7)

Plants coarse, to 6 cm long; main axes to 500 μm diam, setaceous with spine-like adventitious branchlets to 1 mm long; pericentral cells 4; branches arising in axils of trichoblasts; trichoblasts abundant, conspicuous and dichotomously branched to 6 orders; decumbent branches producing rhizoids which remain in open connection with pericentral cells; older axes with rhizoidal cortication; branching widely divergent, subdichotomous; tetrasporangia distended, to 80 μm diam, in short, spiral series in branchlets.
Distribution: Polysiphonia echinata is reported in the northern Gulf of Mexico from Florida (Taylor 1928; Dawes 1974), Louisiana (Humm and Darnell 1959; Kapraun 1974), and Texas (Edwards 1970b).
Specimens studied: DK-*s.n.*, tetrasporic epiphytic on *Halodule wrightii* in Redfish Bay, Aransas Pass, 12 June 1978.

Polysiphonia flaccidissima Holienberg (Figs. 8–9)

Plants minute; extensive creeping system giving rise to filaments to 1 cm tall; pericentral cells 4; erect and prostrate axes with radial development of branch primordia; scar cells giving rise to adventitious branches; rhizoids cut off from the proximal end of pericentral cells. Reproductive material not seen.

This species, previously unreported from the Port Aransas area, was found in the sublittoral growing with *P. subtilissima* on the Fulton Harbor breakwater. *Polysiphonia* flaccidissima resembles diminutive *P. havanensis*, but is clearly distinguished in that it has rhizoids cut off from the pericentral cells, where as in the latter, rhizoids remain in open connection.
Distribution: *Polysiphonia flaccidissima* occurs throughout the central Pacific (Hollenberg 1968a), the Pacific coast of North America (Hollenberg 1942; Hollenberg and Norris 1977), and has been reported from North Carolina (Brauner 1975).
Specimens studied: DK-*s.n.* sublittoral on breakwater, Fulton Harbor, 20 June 1978.

Polysiphonia macrocarpa Harvey in Mackay (Figs. 10–12)

Plants minute, forming entangled mats to 1 cm tall, reddish-brown to black; erect filaments sparsely subdichotomously branched; branches in erect filaments replacing trichoblasts in development; segments to 40 μm diam, 2–3 diam long; pericentral cells 4; trichoblasts scarce, apical cell conspicous; prostrate axes to 60 μm diam, giving rise to erect filaments endogenously, and exogenously from apically derived primordia with delayed development; rhizoids abundant, forming from the middle of pericentral cells and remaining in open connection with them; tetrasporangia to 80 μm diam, swollen, in long straight series from the middle to the tips of erect filaments.

This species, previously unreported from the Port Aransas area, was found in the sublittoral growing with *P. subtilissima* and *P. boldii* on the Fulton Harbor breakwater. Although it shares a creeping, matted habit with the above species, it is easily distinguished from *P. boldii* which has 6 pericentral cells, *P. subtilis-*

sima which has radial development of branches in prostrate axes, while *P. macrocarpa* gives rise to unilateral filaments from prostrate axes, producing a dorsiventral habit.

Distribution: *Polysiphonia macrocarpa* is reported from the tropical western Atlantic (Børgesen 1918; Taylor 1960), Brazil (Filho and Ugadim 1976), North Carolina (Kapraun 1977), England (Batten 1923), the Atlantic and Mediterranean coasts of Europe (Harvey 1846; Gayral 1966; Ardre 1970), Mauritius (Indian Ocean) and Pacific Australia (Ardre 1970).

Specimens studied: Dk-*s.n.* tetrasporic, sublittoral on breakwater, Fulton Harbor, 20 June 1978, and Port Aransas jetty, 12 July 1978.

Polysiphonia subtilissima Montagne (Figs. 13–15)

Plants olive to purple, soft, forming dense tufts 2–4 cm tall; branches replacing trichoblasts in development; pericentral cells 4; erect and prostrate axes with radial development of branch primordia; trichoblasts scarce with few dichotomies; erect filaments subdichotomously branched; 60–80 μm diam; scar cells giving rise to adventitious branches; prostrate filaments 80–100 μm diam; rhizoids developing from the middle of pericentral cells and remaining in open connection with them; tetrasporangia swollen, to 60 μm diam, in long, straight series of 15–20.

In this study, *P. substilissima* was found in abundance on eulittoral rocks on the Port Aransas jetty as well as in Redfish bay, while in a previous ecological survey of the algae in the Port Aransas area (Edwards and Kapraun 1973), it was restricted to Aransas Bay.

Distribution: *Polysiphonia subtilissima* occurs in the western Atlantic from New England (Fralick and Mathieson 1975), Florida (Dawes 1974), the West Indies (Taylor 1960), Brazil (Filho and Ugadim 1976), and the Central Pacific (Hollenberg 1968a) and Peru (Dawson 1964).

Specimens studied: DK-*s.n.* tetrasporic, sublittoral on breakwater, Fulton Harbor, 30 June 1978, and the Port Aransas jetty, 12 July 1978.

Polysiphonia tepida Hollenberg (Figs. 16–17)

Plants dark red, matted, with erect filaments to 2 cm tall; prostrate filaments to 100 μm diam, attached to the substratum by unicellular rhizoids cut off from the distal end of pericentral cells; erect filaments to 60 μm diam, developing radially from prostrate axes with upturned apices; segments 1–2 diam long, with 7 (—8) pericentral cells; branches in erect filaments clearly originating in the axils of trichoblasts. Reproductive structures not seen in this study.

Polysiphonia tepida bears a superficial resemblance to perennating axes of *P. denudata* in that they share a burgundy color, branches arising in the axils of trichoblasts, and rhizoids cut off from pericentral cells. However, *P. tepida* has 8 (—7) pericentral cells while *P. denudata* has 6 (—5). This characteristic is easily determined in transection or by separating the cells in 1% HCl on a microscope slide.

Although this species was found to be common during a previous ecological survey of the algae in the Port Aransas area (Edwards and Kapraun 1973), it

was not encountered during this study. Changes in species composition and abundance from year to year have been previously reported for similar shallow bay environments (Conover 1964; Phillips 1960).
Distribution: *Polysiphonia tepida* is reported from the western Atlantic from North Carolina (Kapraun 1977), Florida (Dawes 1974), Texas (Edwards and Kaprun 1973), and from Hawaii (Hollenberg 1968b).
Specimens studied: PE-*s.n.* sublittoral on jetty, Port Aransas, 4 July 1968.

Polysiphonia gorgoniae Harvey (Figs. 18–23)

Plants light brown, erect to 2 cm tall; basally attached by numerous lobed rhizoids cut off from pericentral cells; erect filaments to 200 μm diam, sparsely dichotomously branched, with a few spine-like branchlets; older branches becoming decumbent, attached by rhizoids cut off from the distal end of pericentral cells; pericentral cells 4; branches arising in the axils of trichoblasts; tetrasporangia swollen, to 60 μm diam, in long spiral series of 10–15 in branch tips; pericarps sessile or short-stalked, nearly spherical at maturity, to 250 μm diam; spermatangial branches oblong 25–30 $\times$ 140–160 μm, subtended by a branched trichoblast.

In several respects, *P. gorgoniae* appears to be a diminuitive *P. echinata*. Both species have branches arising in axils of trichoblasts, rhizoids cut off from pericentral cells, and an essentially erect habit. However, *P. echinata* produces an abundance of spine-like simple or forked adventitious branchlets while *P. gorgoniae* is little branched. Also, *P. echinata* produces greatly distended tetrasporangia in short spiral series of 6–8, while *P. gorgoniae* forms smaller tetrasporangia in slightly swollen, long spiral series of 10–15.
Distribution: Polysiphonia gorgoniae is reported from the tropical western Atlantic including the Bahamas (Howe 1920), Florida (Dawes 1974), and Texas (Edwards and Kapraun 1973).
Specimens studied: DK-*s.n.* male, female, tetrasporic, epiphytic on *Halodule wrightii*, Redfish Bay, Aransas Pass, 12 June 1978.

Polysiphonia denudata (Dillwyn) Greville ex Harvey in W. J. Hooker (Figs. 24–27)

Plants dark red, erect to 6 cm tall from a discoidal base; erect filaments dichotomously branched; branches widely divergent, becoming decumbent in older parts and attached to the substratum by rhizoids cut off from the proximal end of pericentral cells; branches arising in axils of trichoblasts; pericentral cells 5 (–6); spermatangial branches long, conical, with a sterile tip cell and subtended by a branched trichoblast; pericarps spherical, 200–250 μm diam; tetrasporangia to 50 μm diam, in long series in the upper branches.

It is characteristic of *P. denudata* that developmentally, vegetative branches arise in the axils of trichoblasts. In this study, numerous male gametophytes were observed in which vegetative branches developed in the axils of spermatangial stalks (Fig. 25). Additionally, spermatangia are described for this species elsewhere as being tipped by several elongate sterile cells forming a filiform tip

(Lauret 1967; Kapraun 1977), while plants observed in this study had a solitary sterile tip cell (Fig. 25).
Distribution: Polysiphonia denudata is reported from the Atlantic North America (Nova Scotia to the Gulf of Mexico and Caribbean) by Taylor 1957, 1960, Atlantic Europe, Morocco and the Mediterranean (Andre 1970), West Africa (Lawson and John 1977), Australia (Andre 1970) and India (Rao 1967, as *P. variegata*).
Specimens studied: DK-*s.n.* male, female, tetrasporic, sublittoral on Port Aransas jetty, 13 June 1978.

Polysiphonia boldii Wynne et Edwards (Figs. 28–33)

Plants densely tufted, reddish-brown, consisting of erect filaments 1–2 cm tall from an extensive creeping base; erect filaments to 200 μm diam, segments usually less than 1 diam long, with 6 (–7) pericentral cells; trichoblasts conspicuous, plumose, dichotomously branching to 4 or more orders; rhizoids developing from the middle of pericentral cells and remaining in open connection with them; prostrate filaments to 150 μm diam, giving rise endogenously to erect axes in a unilateral fashion; branches in erect filaments replacing trichoblasts in development; tetrasporangia to 60 μm diam, in straight or offset series in slightly swollen branch tips; pericarps oval to spherical, 300–250 μm diam, 400–450 μm long; spermatangial branches long-conical, to 75 μm diam and 300 μm long, arising in pairs (more rarely singly or in threes) from an entire trichoblast promordium.

These species, recently described from Texas coast material (Wynne and Edwards 1970), bears close morphological resemblance to *P. hemisphaerica* Areschoug from Scandinavia. Rueness (1971, 1973) investigated the relationship of these two taxa and reduced *P. boldii* to varietal status as *P. hemisphaerica* Aresch. var. *boldii* (Wynne *et* Edwards) Rueness. However, the disjunct distributions and reported phenologies of each suggest that these two entities are genetically isolated in nature, and thus could be considered subspecies (Stebbins 1950; Rueness 1978).

Specimens examined in this study showed the greatest variation in the morphology of spermatangial branches. Typically, male structures developed from an entire trichoblast promordium on a unicellular base, and lacked any specialized tip cells. However, individuals were observed with 3–4 celled terminal hairs or sterile tip cells, and with one of the spermatangial branches failing to become fertile, producing simulated "subtending trichoblasts." Similar variations in spermatangial branches have been reported for other species of *Polysiphonia*, e.g. *P. scopularum* (Hollenberg 1968a) and *P. nigrescens* (Rosenvinge 1923).
Distribution: In the western Atlantic, *Polysiphonia boldii* occurs in Texas (Wynne and Edwards 1970), the Florida Keys and Bermuda (Kapraun unpublished data).
Specimens studied: DK-*s.n.* male, female, tetrasporic, sublittoral on breakwater, Fulton Harbor, 20 June 1978.

DISCUSSION

The genus *Polysiphonia* is delimited from other members of the Rhodomelaceae, at least in part, by its radial symmetry and erect habit (see e.g., Hollenberg 1942, 1968a). Three of the nine species in this study conform to this definition while others exhibited some degree of prostrate development as discussed by Kapraun (1977) and Rueness (1971): a) Plants initially erect from a discoidal base, but forming secondary rhizoidal attachment from decumbent branches (*P. denudata*, *P. gorgoniae*, *P. echinata*); b) Plants developing a horizontal system from an erect apex (*P. tepida*, *P. havanensis*, *P. flaccidissima*); and c) Plants developing a prostrate system from a horizontal apex, typically devoid of trichoblasts (*P. macrocarpa*, *P. subtilissima*, *P. boldii*).

In species which bear a trichoblast or branch from each segment, tetrasporangia form in a left-handed spiral toward the apex (Segi 1951), as was observed in *P. havanensis*. In species which have segments without trichoblasts, branches, or their primordia, tetrasporangia form in straight or offset position as was observed in *P. subtilissima*, *P. boldii*, and *P. denudata*.

None of the nine *Polysiphonia* species encountered in this study is endemic to Texas. Four species, *P. boldii*, *P. havanensis*, *P. echinata*, and *P. gorgoniae* have primarily tropical Caribbean distributions, and three species, *P. flaccidissima*, *P. subtilissima*, and *P. tepida* are reported from tropical and warm temperate regions of the Pacific and Atlantic oceans. Only two species, *P. denudata* and *P. macrocarpa*, are essential cosmopolitan, occurring in temperate and tropical seas throughout the world.

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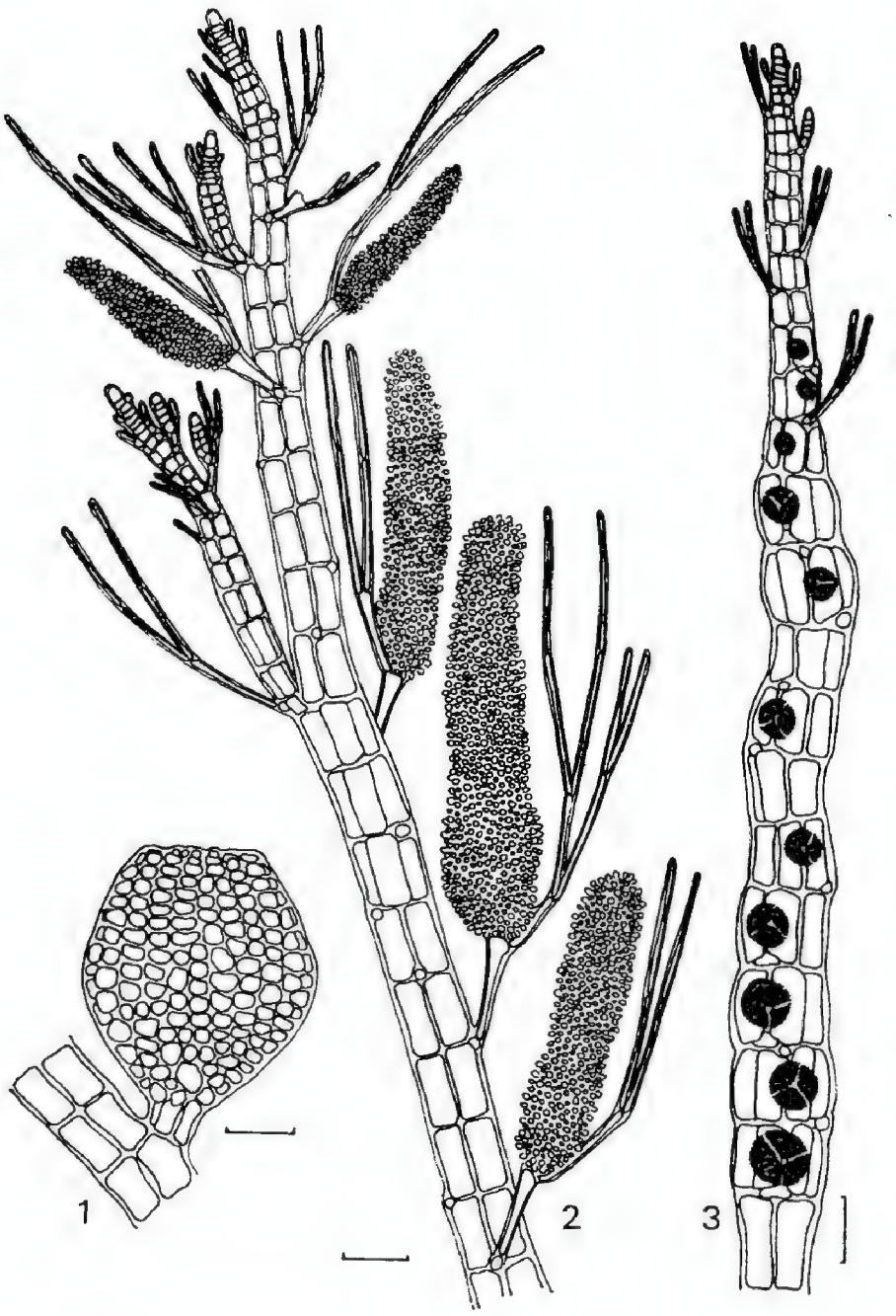
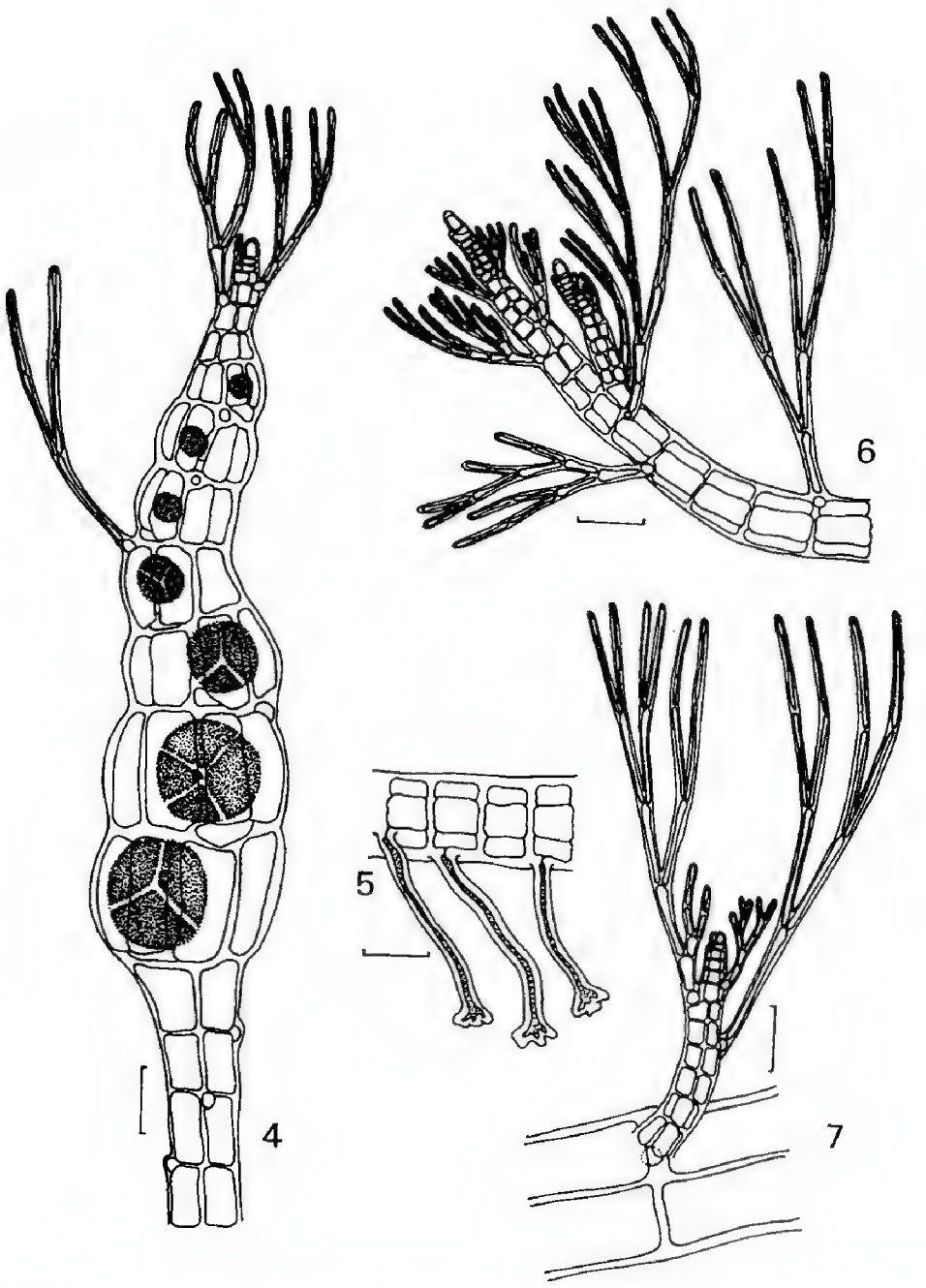
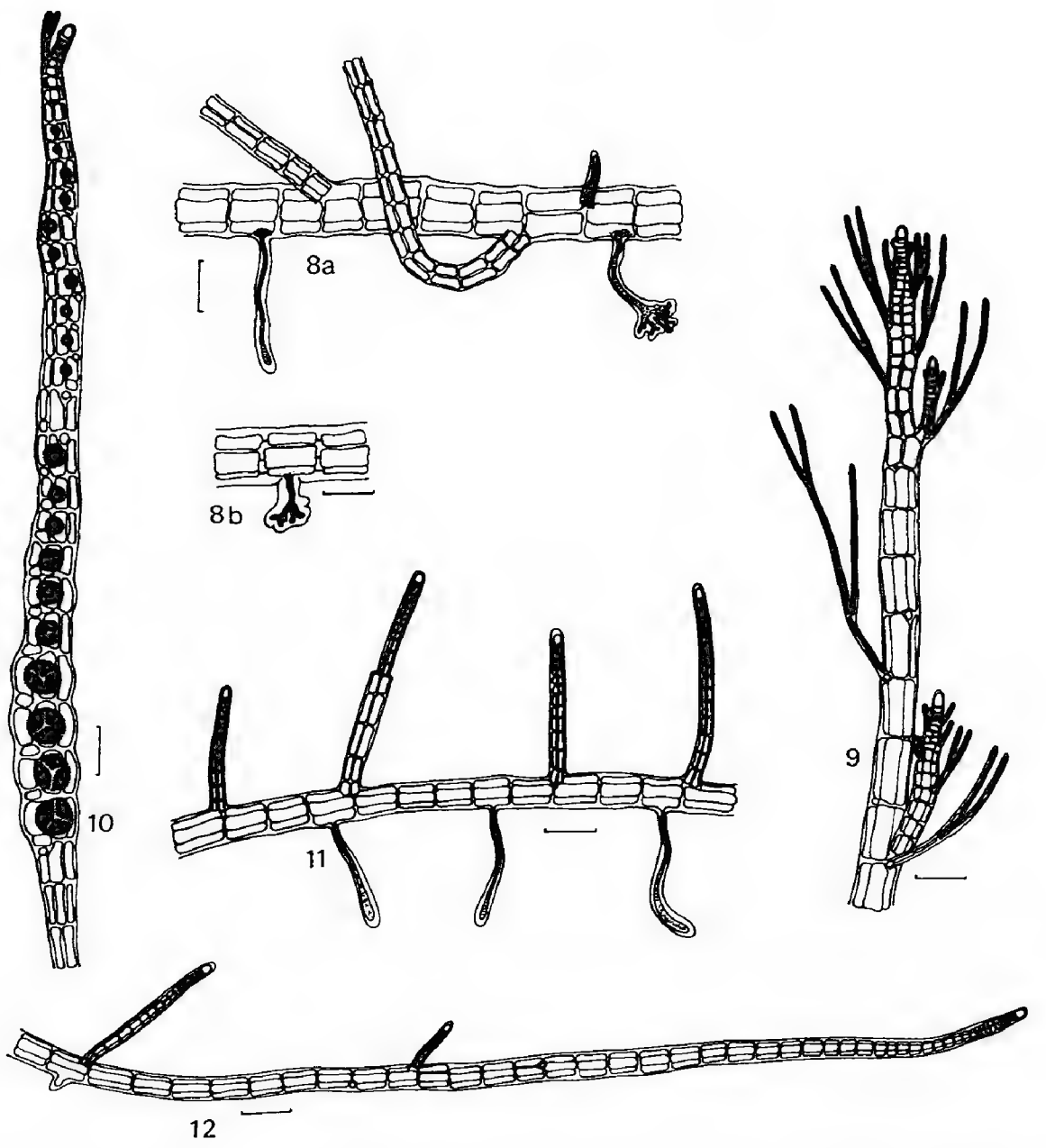


FIGS. 1–3. *Polysiphonia havanensis*. Fig. 1. Mature pericarp. Fig. 2. Spermatangial branches. Note branches in axils of trichoblasts. Fig. 3. Tetrasoporangia in spiral series. Scale = 50 μm.

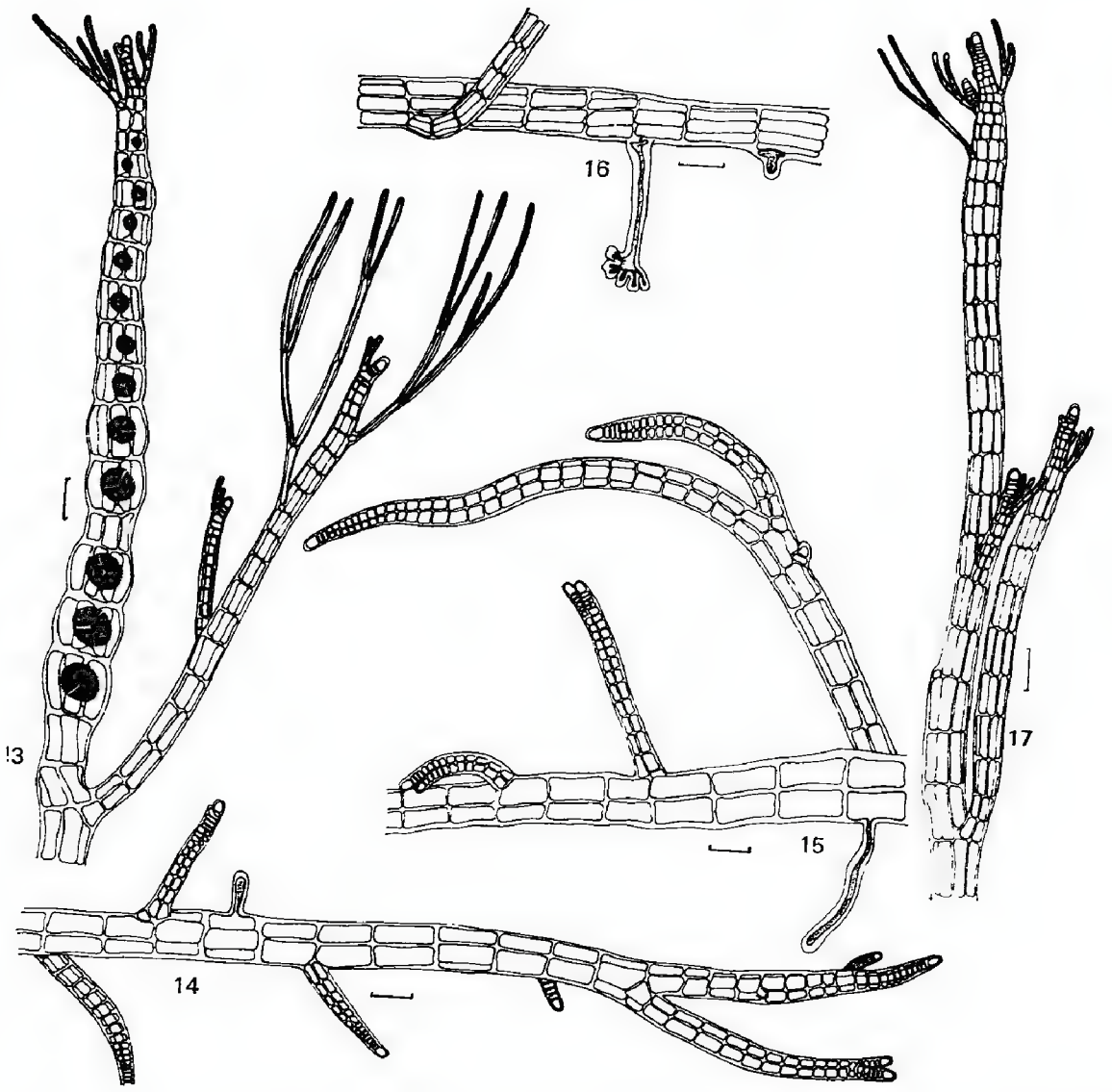


FIGS. 4–7. *Polysiphonia echinata.* Fig. 4. Tetrasporangia in short spiral series. Fig. 5. Rhizoids cut off from pericentral cells. Fig. 6. Apex with branch arising in axil of trichoblast. Fig. 7. Adventitious branchlet. Scale = 50 μm.



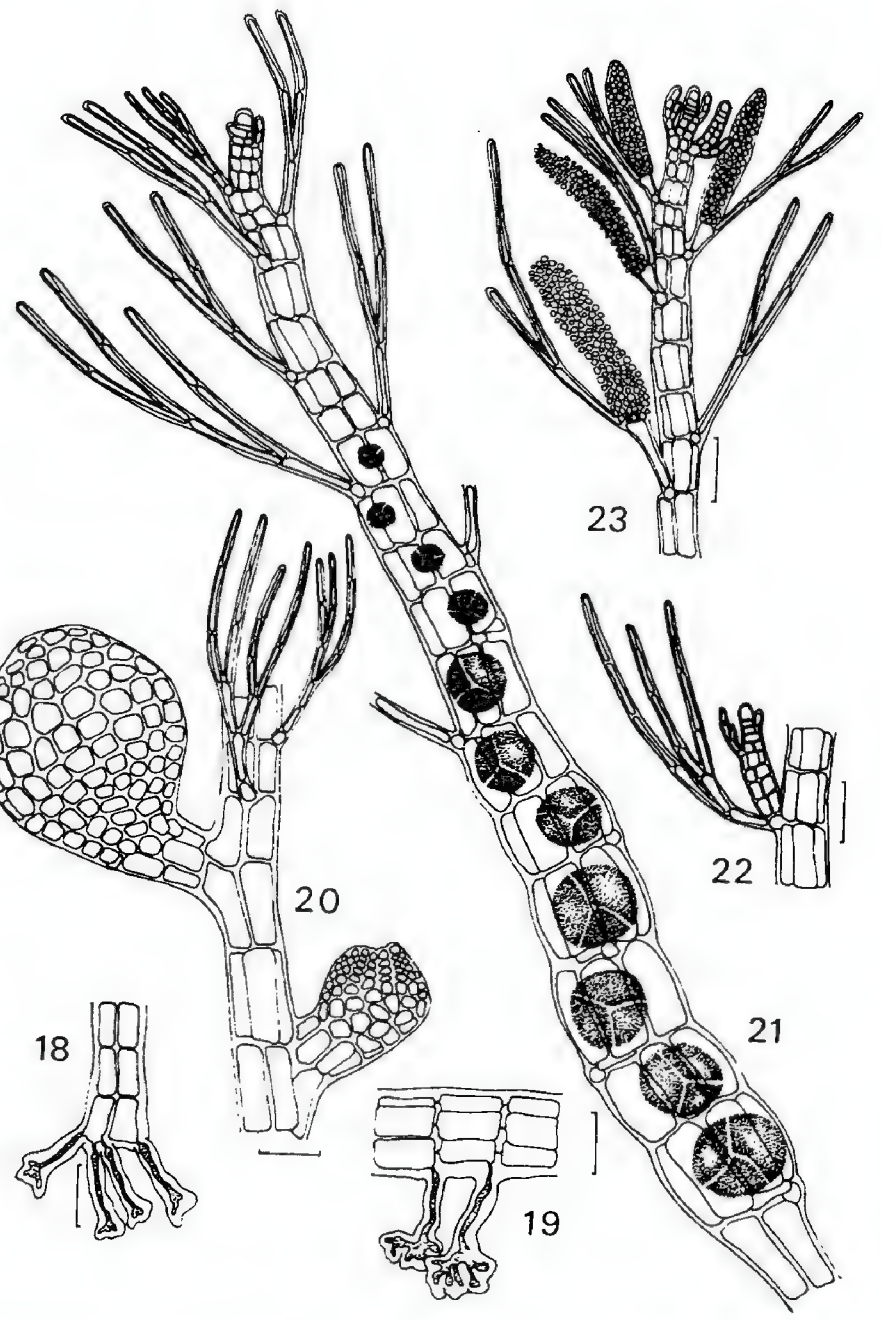
Figs. 8–9. *Polysiphonia flaccidissima.* Fig. 8 a and b. Horizontal axis with rhizoids remaining in open connection to pericentral cells. Fig. 9. Apex with branches developing in axils of trichoblasts. Scale = 50 μm.

Figs. 10–12. *Polysiphonia macrocarpa.* Fig. 10. Tetrasporangia in long straight series. Fig. 11. Erect filaments developing at regular intervals. Note rhizoids in open connection to pericentral cells. Fig. 12. Horizontal apex with unilateral development of erect branches. Scale = 50 μm.

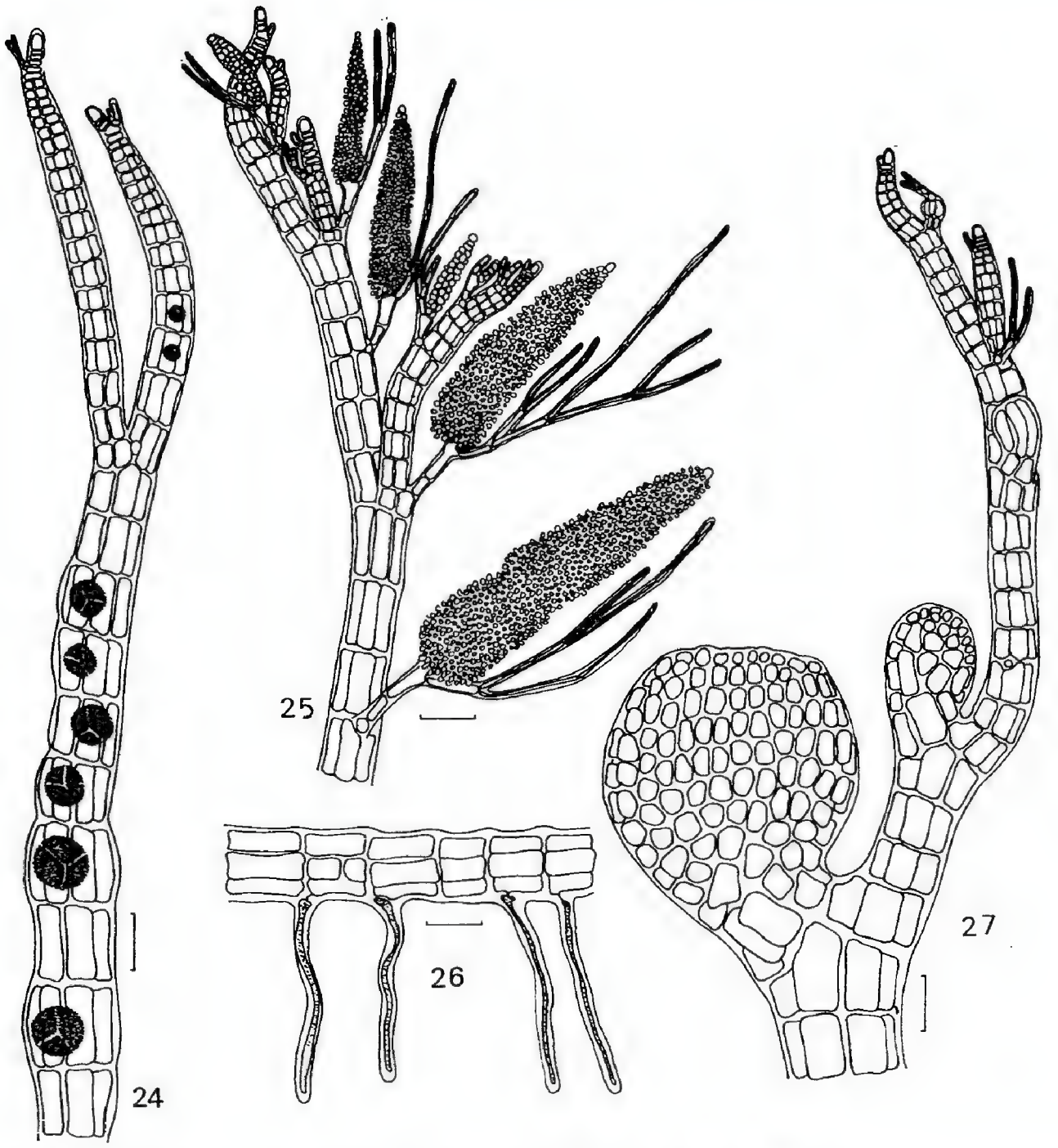


Figs. 13–15. *Polysiphonia subtilissima*. Fig. 13. Tetrasporangia in straight series. Figs. 14–15. Horizontal axes with radial development of erect branches. Scale = 50 μm.

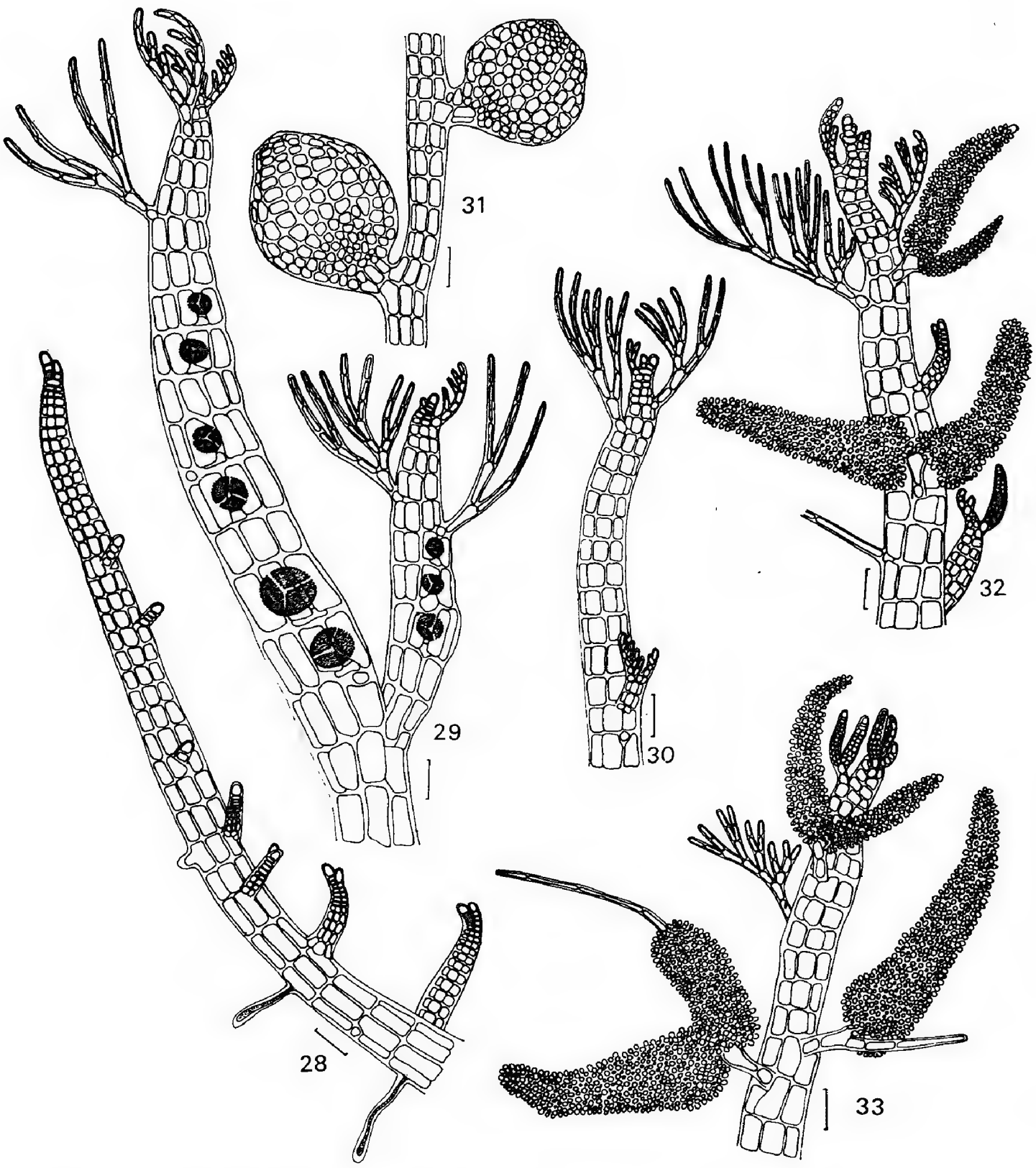
Figs. 16–17. *Polysiphonia tepida*. Fig. 16. Horizontal axis with rhizoids cut off from pericentral cells. Fig. 17. Apex with branches developing in axils of deciduous trichoblasts. Scale = 50 μm.



FIGS. 18–23. *Polysiphonia gorgoniae*. Fig. 18 Plant base with cluster of rhizoids. Fig. 19. Decumbent branch with adventitious rhizoids cut off from pericentral cells. Fig. 20. Pericarps. Fig. 21. Tetrasporangia in spiral series. Fig. 22. Branch developing in axil of trichoblast. Fig. 23. Spermatangial branches. Scale = 50 μm.



FIGS. 24–27. *Polysiphonia denudata.* Fig. 24. Tetrasporangia. Fig. 25. Spermatangial branches with vegetative branches developing in their axils. Fig. 26. Decumbent branch with rhizoids cut off from pericentral cells. Fig. 27. Pericarps. Scale = 50 μm.



FIGS. 28–33. *Polysiphonia boldii*. Fig. 28. Horizontal axis with unilateral development of erect filaments. Fig. 29. Tetrasporangia. Fig. 30. Apex with branch replacing trichoblasts in development. Fig. 31. Pericarps. Figs. 32–33. Spermatangial branches. Note variability including subtending trichoblasts and terminal filaments. Scale = 50 μm.

RANGE EXTENSION TO TEXAS FOR *TAPHROMYSIS BOWMANI* BACESCU (CRUSTACEA: MYSIDACEA) WITH NOTES ON ITS ECOLOGY AND GENERIC DISTRIBUTION[1]

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ABSTRACT

Twenty specimens of *Taphromysis bowmani* Bacescu were collected in the Upper Laguna Madre near Flour Bluff, Texas from June, 1976 through February, 1977. This is a major western extension for this species which previously was known only from Florida. A complete literature review and notes on the ecology of *T. bowmani* and its generic distribution are presented.

INTRODUCTION

Little is known of the ecology of *Taphromysis bowmani*, a mysid previously known only from Florida. Bacescu (1961) described the species from Biscayne Bay. The salinity was not given but *T. bowmani* was later collected from the same site in salinities ranging from 13.3 to 26.0‰. The substrate was fine quartz sand with sparse patches of *Thalassia* and *Halodule*. Bacescu (1961) also reported the species from fresh water in the Wakulla River and in water believed to be brackish to marine in Bayou Southerland.

The Smithsonian Institution collections included specimens of *T. bowmani* collected by W. Belk from the Escambia River in October, 1952 and March, 1953 and from Bridge Creek, near Perdido Bay in March, 1953. Information concerning water temperature and salinity was not available (T. E. Bowman, personal communication).

Brattegard (1969) collected *T. bowmani* from Biscayne Bay, New Port Richey and from Buttonwood Channel, North River, Rookery Branch and Whitewater Bay in the Everglades. Salinities ranged from 0.0 to 32.5‰ and temperatures ranged between 18.5 and 30.0 C.

Odum and Heald (1972) reported *T. bowmani* from the North River, a mangrove estuary of the Florida Everglades. It was the second most common mysid after *Mysidopsis almyra* Bowman and occurred throughout the year in salinities ranging from 1.0 to 26.2‰.

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Subrahmanyam, Kruczynski and Drake (1976) collected *T. bowmani* from St. Marks and Wakulla marshes in salinities ranging from 10.0 to 28.0‰ and temperatures ranging from 5.0 to 25.0 C. Abundances were greatest in the winter and spring.

Beck (1977) reported a reproducing population of *T. bowmani* from fresh water of the Wakulla River in January, February, March–June, August and December. The greatest number were collected in shallow submerged grass beds of *Najas guadeloupensis* and *Ruppia maritima.*

This study presents information on the ecology, reproduction, and morphological variation of *T. bowmani.* The distribution of *T. bowmani* and its only congener, *T. louisianae*, are discussed.

MATERIALS AND METHODS

Monthly samples were collected from February, 1976 through February, 1977 at the Barney Davis Electric Generating Station near Flour Bluff, Texas (27°36′N and 97°18′W) from intake screens having 0.5 mm mesh. The substrate of the collecting area is predominately fine quartz sand with *Halodule, Ruppia* and *Halophila* as associated flora.

All specimens were preserved in 10% formalin and later stored in 70% isopropanol. Water temperatures were recorded from a continuous temperature recorder located in the intake canal and salinity was detemined by use of a Goldberg refractometer. Length measurements were recorded to the nearest 0.1 mm with an ocular micrometer.

RESULTS AND DISCUSSION

Ecology

The collection of 20 *Taphromysis bowmani* in the Upper Laguna Madre extends the known geographic range of this species approximately 1300 km westward. Specimen data from the Texas coast are shown in Table 1.

Of the 20 specimens collected, 12 were female (5 ovigerous, 5 mature and 2 immature) and 8 were male (all mature). Marsupia of ovigerous females contained 4–9 eggs or young as compared to 7–10 and 6–17 eggs and young reported by Bacescu (1961) and Beck (1977), respectively. Lengths ranged from 5.0 mm in the summer to 11.0 mm in the winter with the largest male being 8.5 mm

TABLE 1

Data on *T. bowmani* Bacescu collected at the Barney Davis power plant near Flour Bluff, Texas.

Collection	Specimens Collected	M	F	Marsupium Developed	Egg/Young Present	Mean Length (mm)	Temp. C	Sal. o/oo
6/22/76	5	4	1	0	0	5.6	27.2	38.9
7/30/76	1	0	1	1	0	7.5	29.4	34.0
8/29-30/76	5	2	3	3	2	6.7	29.3	34.0
9/29/76	3	1	2	1	0	5.3	25.5	32.0
1/29-30/77	3	0	3	3	2	7.8	9.4	20.9
2/27-28/77	3	1	2	2	1	10.0	15.3	18.9

TABLE 2

Comparison of morphological characteristics between *T. bowmani* from Texas and Florida.

Morphological Characteristics	Texas		Florida		
	male	female	male*	female*	Brattegard 1969
No. of lateral telson spines	6-9	7-10	6-9	7-10	8-10
No. of laminae in telson sinus	15-23	16-24	15-26	16-25	14-20
Ratio of apical article to entire antennal scale	$\frac{1}{9}-\frac{1}{10}$	$\frac{1}{9}-\frac{1}{11}$	$\frac{1}{9}-\frac{1}{11}$	$\frac{1}{9}-\frac{1}{11}$	$\frac{1}{10}$

*includes Bacescu's data (1961) and specimens from Tampa Bay and the Wakulla River

and the largest ovigerous female being 11.0 mm. In accordance with data from Price (1976) and Compton (1977), the smallest *T. bowmani* were collected in the warmer months and the largest were found in the winter. Beck (1977) found that the mean lengths of gravid females decreased from March (9.0 mm) to June (7.9 mm).

The majority of *T. bowmani* were collected in the summer and early fall in the present study. Subrahmanyam *et al.* (1976) found that abundances were greatest in the winter and spring; however, since most specimens were collected with an 8 mm mesh seine, the smaller mysids, which may have occurred in large numbers during the warmer months, were not retained. Thus, the winter-spring peak might be apparent rather than real. Price (1976) and Compton (1977) found that ovigerous females of three mysid species along the Texas coast (*Mysidopsis almyra* Bowman, *M. bahia* Molenock, *M. bigelowi* Tattersall) were largest in the winter and early spring and were replaced by progressively smaller individuals in the late spring and summer. These mysid species around Galveston Island, Texas displayed similar cycles of rapid reproduction and larger numbers during the summer months and slow reproduction and low numbers during the winter months (Price 1976).

Collection records of *T. bowmani* indicate that it may breed throughout the year. Ovigerous females were collected in August, January and February in the present study (Table 1) and were found in February, March, May–July and November by Brattegard (1969). Beck (1977) collected ovigerous *T. bowmani* in March–June, August and December, 1975, and in January and February, 1976 and noted that gravid females comprised the greatest percentage of the March to June samples (20.0 to 32.6%).

Comparison of morphological characteristics indicates little difference between Texas and Florida specimens (Table 2). Although chromatophore patterns were the same for both populations, preserved specimens from Florida exhibited heavier pigmentation than the Texas specimens.

General Distribution

Taphromysis louisianae Banner, the only other congener, occurs from the Galveston Bay area on the Texas coast to the Florida panhandle. Banner (1953) described *T. louisianae* from specimens collected in fresh water from Gueydan, Louisiana. It has also been reported from the Atchafalaya Basin, Louisiana (P. Newman, personal communication). The Smithsonian Institution has two samples of this species from Alabama which are believed to be from fresh water (T. E. Bowman, personal communication). In Texas, *T. louisianae* was reported from Alligator and Oyster Lakes near Galveston in waters having a salinity range from 0.0 to 26.0 ‰ (Conte 1972), from Trinity Bay having a salinity range from 0.3 to 3.1 ‰ (Kalke 1972) and from the Neches River System in fresh water (Harrell, Ashcraft, Howard and Patterson 1976). Holland, Maciolek, Kalke and Oppenheimer (1975) reported a single specimen from Copano Bay, but reexamination of this specimen by one of the present authors revealed the mysid to be too immature for specific identification.

Taphromysis bowmani appears to exhibit a disjunct distribution, Florida and Texas, with *T. louisianae* occupying the intervening states. This apparent distribution may represent our imperfect knowledge of the fauna of the northern Gulf coast or differences in environmental requirements of the two species. Further investigations are needed along the Gulf coast to answer these questions.

ACKNOWLEDGMENTS

We wish to thank Drs. Thomas Bowman, Fred Conte and Carl Wood for their suggestions, Dr. Thomas Bowman for verifying specimen identifications and supplying collection information from Escambia County and Thomas Beck for supplying specimens from the Wakulla River.

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EFFECTS OF TEMPERATURE AND SALINITY ON THE GROWTH OF THE BENTHIC DIATOM *NITZSCHIA OVALIS* ARNOTT (BACILLARIOPHYCEAE)

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ABSTRACT

Temperature and salinity tolerance of *Nitzschia ovalis* and the effects of combinations of these factors on its growth show that it is a eurythermal and euryhaline benthic diatom. The effect of these environmental factors on benthic microflora is seldom studied *in vitro*. *N. ovalis*, reported here for the first time from the Gulf of Mexico, grew well at salinity levels from 8 to 53 ‰ and temperature levels from 12 to 36 C. Maximum growth rates occurred at combinations of 28, 30, 32 C and 28, 32 ‰ salinity. The implication of these findings to natural populations of *N. ovalis* are discussed.

INTRODUCTION

Records of the benthic marine diatom, *Nitzschia ovalis* Arnott indicate that this species is primarily a cold to temperate water form. *N. ovalis* has been reported from the Arctic Ocean (Cleve and Grunow 1880), the North Sea (Hustedt 1939), Northern Alaska (Patrick and Freese 1960), Nova Scotia (North and Stephens 1972), the Baltic Sea (Simonsen 1962), and South Africa (Cholnoky 1963; Giffen 1967, 1971, 1973, 1975). Mills (1934) listed two varieties of *N. ovalis*: 1) v. *antarctica* described from antarctic waters by M. Peragallo and 2) v. *major* from Greenland by Ostrup. Only one known report of *N. ovalis* from tropical waters exists (Foged 1966).

Despite Arnott's original listing of the type locality of *N. ovalis* as fresh water near Durham, England (Van Heurck 1885, pl. 69, fig. 36), *N. ovalis* is considered a mesohaline to euryhaline form (Hustedt 1930, 1936; Simonsen 1962; Round 1971) occurring in both standing and flowing saline waters (Round 1971). Krasske (1930, cited in Hustedt, 1930) reported *N. ovalis* in salt pits which were probably areas of high salinity. *N. ovalis* has seldom been reported from fresh water (Foged 1966).

Thus, when a specimen identified as *N. ovalis* was isolated from the nearshore waters of the Gulf of Mexico at Galveston Island, Texas and later reported from the coastal waters and estuaries of the Galveston Bay system (personal observation, G. A. Fryxell and J. D. Zotter, personal communication), the question arose

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as to whether this isolate represented a distinct taxon or a physiological race of the diatom *Nitzschia ovalis*. One of us (LKM) compared the identification of the Gulf of Mexico isolate to the type species (Type slide no. 414, Van Heurck museum, Antwerp, Belgium). Our ecotype of *N. ovalis* is smaller than the type (7–9 μm as compared to 12–20 μm), but the hyaline appearance and the overall valve outline are consistent with the type.

The present paper includes results from experiments designed to determine the temperature and salinity tolerance levels and optima and the interaction of these two factors on the growth of our isolate of *N. ovalis*. Although the effects of temperature and salinity have been explored extensively with phytopkankton species (Smayda 1958, 1969; Braarud 1961, 1962; Guillard and Ryther 1962; Hulbert and Guillard 1968; Ignatiades and Smayda 1970; Durbin 1979; Holt and Smayda 1974; Paasche 1975; Tomas 1978), little is known of the response of benthic microflora to the same two environmental factors.

A halobion system has been devised to characterize the distribution of benthic diatoms (Kolbe 1927; Hustedt 1957), and salinity gradients have been correlated with diatom distribution in several neritic and estuarine areas (McIntire and Overton 1971; Round 1971; Amspoker 1977). Yet, *in vitro* studies of benthic diatoms reveal a broad salinity tolerance for those species examined. The growth rates of four benthic diatoms and mixed populations of diatoms taken from the mud and sand flats of the Eems-Dollard Estuary, The Netherlands were evaluated in response to varying salinity (Admiraal 1977b). These estuarine diatoms were tolerant of a wide range of salinities, which contradicted an earlier assumption that salinity was the most important factor determining benthic diatom distribution in this estuary. Williams (1964) had earlier reported similar findings for benthic diatoms from a Georgia salt marsh. In fact, preconditioning of the salinites tested did not improve their response. *In vitro* studies of the effect of temperature on the growth rate of benthic diatoms reveal that the four species tested grew well from 4 to 25 C, but the optimum temperature for growth was similar to the highest temperatures attained by the mud and sand flats from which the diatoms were isolated (Admiraal 1977a).

MATERIALS AND METHODS

N. ovalis was isolated into unialgal culture from a sample taken one meter above the bottom with a van Dorn sampler five miles offshore from Galveston Island, Texas (Lat. 29°17′42″N, Long. 94°39′W), and incubated at 24 C, 28 ‰ salinity, and 1000 f.c. of continuous cool-white fluorescent illumination. Temperature and salinity values for the neritic waters around Galveston Island range from 8 to 30 C and from 12 to 36 ‰ salinity depending on river discharge into Galveston Bay. Stock and experimental cultures were grown in 10 ml of medium in acid cleaned and pretreated borosilicate test tubes. An artificial sea water medium (NH-15, Gates and Wilson 1960) with an additional 5.35 mg/1 Na_2SiO_3 and 200 units of penicillin and 100 μg of streptomycin/ml was used at all times. Stock solutions of major salts (NaCl, KCl, $MgCl_2$, $MgSO_4$, $CaCl_2$) were diluted with double glass distilled water to obtain a suitable range of test salinities. *N. ovalis* was preconditioned to most temperatures and salinities and to each temperature/salinity combination. Experimentation at 38 and 40 C or at 4 ‰ salinity was done by inoculating media with live cells grown at the nearest temperature or salinity.

The average daily division rate was determined for 1) the salinity tolerance experiment, 2)

the temperature tolerance experiment, and 3) the sixty-six different temperature/salinity combinations. The third set of experiments was conducted in two parts. In the first part, six temperature levels (24, 26, 28, 30, 32, and 34 C) and six salinity levels (16, 20, 28, 32, and 36 ‰) were combined. In the second part, five different salinities (12, 14, 40, 50, 60 ‰) and a 28 ‰ salinity control were combined with the same temperature levels as in the first part.

Triplicate media portions were inoculated with ca. 1000 cells/ml from preconditioned stock cultures in exponential growth and incubated under the prescribed test conditions. Media portions were agitated and monitored daily with a Turner Model 111 fluorometer. Growth experiments were terminated with Lugol's preservative after substantial growth was detected by relative fluorescence. The light intensity striking the surface of the tubes was monitored daily with a Gosner Luna-Pro light meter and held constant at 1000 f.c. Culture portions exposed to low salinity and temperature levels required longer incubation periods to reach the log phase of growth. Cell numbers of test portions were counted with a haemocytometer, and the average daily division rate (K) for each incubation period was calculated from

$$K = \ln\left(\frac{C_t}{C_o}\right)\left(\frac{1}{t \ln 2}\right)$$

where C_t and C_o are cell concentrations at times t and o respectively, with C_t representing the mean terminal population for the three replicates. (Smayda 1969). Standard regression analyses were conducted on untransformed data using a Hewlett Packard calculator model 9830A in coordination with a Hewlett Packard 9862 plotter. The data were fitted to a quadratic model in all cases. A Student's t test was performed on paired data from mean growth rates in columns and rows from the temperature/salinity combinations.

RESULTS

N. ovalis tolerated a wide range of salinities from 8 to 81‰ (Table 1, Fig. 1). No growth was detected at 4‰ salinity, but live cells were present in medium with this salinity after 47 days incubation. Growth was good in medium with 8‰ salinity ($K = 1.28$), better in media with 14 to 53‰ salinity ($K = 1.52$–1.75), but was substantially less (approximately 6 fold) in 81‰ salinity medium ($K = 0.24$).

N. ovalis tolerated a wide range of temperatures from 12 to 36 C (Table 2, Fig. 1). No growth occurred or florescence detected at either 38 or 40 C during a two-week test period. Good growth occurred at 36 C ($K = 1.3$), and growth was better at temperatures from 24 to 34 C ($K = 1.73$–1.77). The culture portions exposed to lower temperatures of 12 and 16 C required longer incubation periods before substantial growth was achieved (38 to 23 days respectively). Growth rates at these test conditions were reduced ($K = 0.21$ and 0.32).

The data from the temperature/salinity interaction experiments were similar (Table 3, Fig. 2,3). In the first set of experiments, there were no significant differences between mean growth rates of cells grown in media from 16 to 36‰ salinity using a Student's t test. In the second set of experiments, no significant differences were found between mean growth rates of cells grown in media from 14 to 50‰ salinity. However, K values of cells grown in media with 12 to 60‰ salinity were significantly different ($P < 0.05$) from those at the other salinities. In both sets of experiments, the average daily division rate of cells grown in media of all salinities incubated at 24 C were significantly different ($P < 0.05$) from those incubated at 30 and 32 C. Thus average daily division rates of *N.*

ovalis in media with combinations of 26 to 34 C temperature and 16 to 50 ‰ salinity were not significantly different at the 5‰ level. The maximum mean daily division rates (K = 2.07–2.20) occurred at combinations of 28, 30, 32 C and 28, 32‰ salinity.

The overall growth rates of cells in the second set of experiments were slightly lower than those in the first set of experiments. The growth rates obtained at

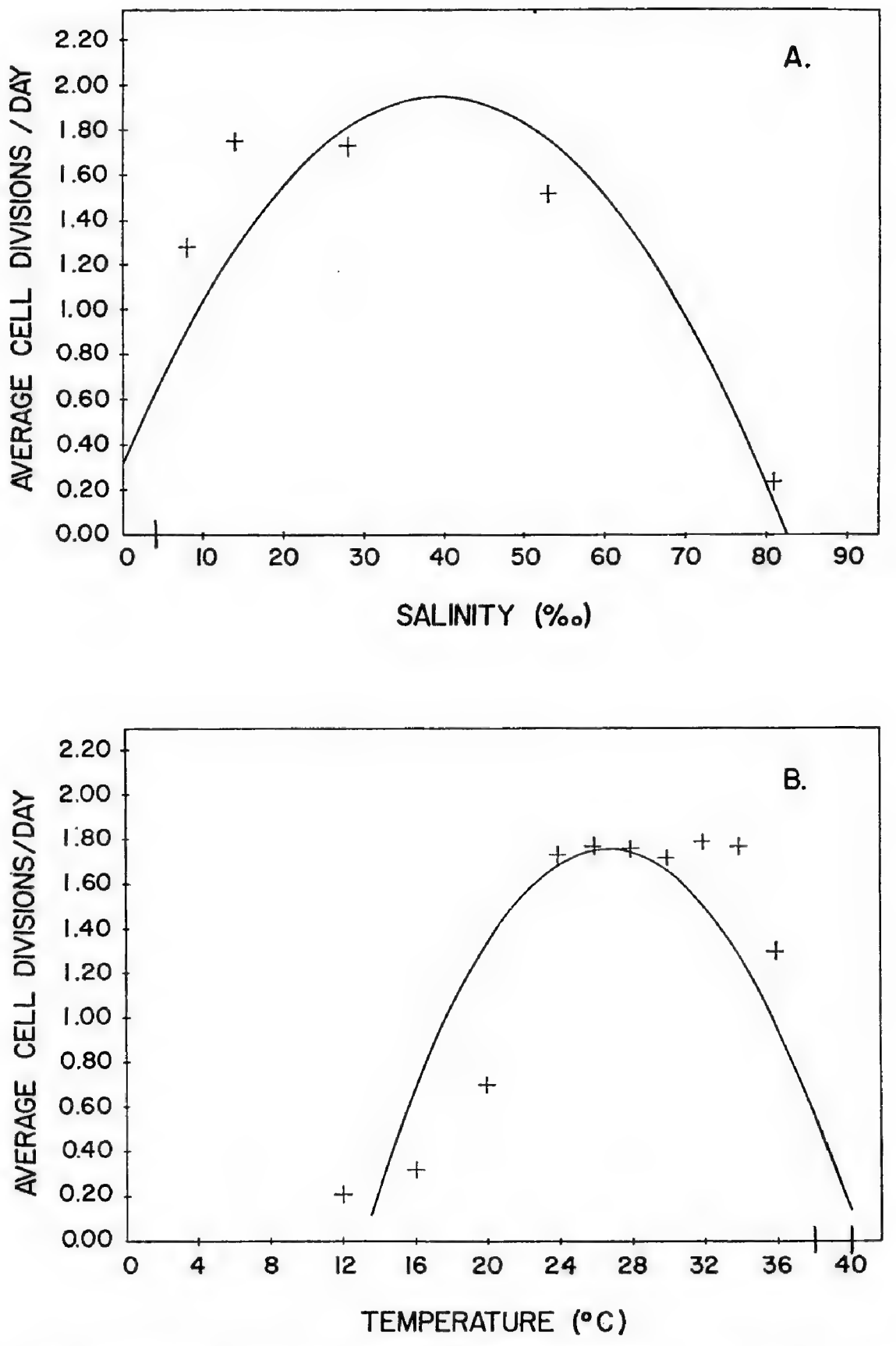

FIG. 1. The average cell divisions/day of *N. ovalis* grown at various (A) salinities at 28 C and (B) temperatures at 28 ‰ salinity.

TABLE 1

Mean daily division rates (K) of *N. ovalis* at various salinities with controlled conditions of 26–28 C and 1000 f.c.

Salinity (‰)	4	8	14	28	53	81
K Values	0.00	1.28	1.75	1.73	1.52	0.24

TABLE 2

Mean daily division rate (K) of *N. ovalis* at various temperatures with controlled conditions of 28 ‰ salinity and 1000 f.c.

T (C)	12	16	20	24	26	28	30	32	34	36	38	40
K Values	0.21	0.32	0.70	1.73	1.77	1.76	1.72	1.79	1.77	1.30	0.00	0.00

14‰ salinity from the first experiment were significantly different from that obtained from cells incubated at 16‰ salinity from the second experiment; while growth rates of cells grown in media with 36‰ salinity from the first experiment were not significantly different from growth rates of cells grown in media with 40 and 50‰ salinity from the second experiment. The growth rates of cells grown in media with 28‰ salinity from both experiments were significantly different ($P < 0.05$) and indicate possible physiological differences between cultures used in the two experiments because light, temperature, salinity, and nutrient concentrations were held constant in both experiments.

Based on these temperature and salinity results (Tables 1, 2, 3; Figs. 1, 2, 3), an optimal salinity range from 16 to 36‰ and an optimal temperature range from 26 to 32 C is suggested for maximum growth of *N. ovalis*.

TABLE 3

Mean daily division rates (K) of *N. ovalis* at various combinations of temperature and salinity with controlled conditions of 1000 f.c.

Temperature (C) Salinity (‰)	24	26	28	30	32	34
12	0.28	0.56	0.66	0.70	0.51	0.53
14	1.10	1.47	1.57	1.55	1.38	0.70
16	1.75	1.96	1.95	2.00	2.05	1.64
20	1.55	1.47	1.74	1.97	2.07	1.39
24	1.55	1.63	1.68	2.16	1.76	0.73
28	1.20	1.62	1.53	1.56	1.59	1.58
28	1.84	1.98	2.07	2.15	2.07	1.75
32	1.73	1.96	2.03	2.20	2.09	1.93
36	1.60	1.64	1.92	1.97	1.92	1.77
40	1.23	1.70	1.54	1.73	1.74	1.66
50	1.17	1.54	1.54	1.51	1.60	1.58
60	0.65	1.10	1.19	1.42	1.01	1.47

DISCUSSION

Results of the temperature experiments indicate that *N. ovalis* displays strong eurythermal characteristics. *N. ovalis* grew at temperatures from 12 to 36 C. The growth of *N. ovalis* at 12 C suggests that it should be able to grow at a reduced rate in temperate areas but should flourish in areas of higher temperatures. The paucity of reports of this diatom from subtropical to tropical areas (see Conger, Fryxell, and El-Sayed 1972) is surprising in view of these temperature tolerances, but because of its small size the species may have been overlooked. It is also possible that some other factor has limited its distribution. The highest temperature at which *N. ovalis* grew (36 C) is greater than the temperature of most natural habitats, even in the tropics. Several groups of algae, including diatoms, have been cultured at temperatures higher than those of their natural habitats (Hulburt and Guillard 1968; Smayda 1969; Admiraal 1977b). Smayda (1969) points out that this may be a common discrepancy between *in vivo* and *in vitro* results. Nevertheless, this tolerance of high temperatures may enable *N. ovalis* to survive and flourish in tropical waters, estuaries, or tidal pools with high temperature levels. *N. ovalis* occurred in Swan Marsh, Galveston Bay in bloom proportions (7.7×10^3 cells/ml) in waters with a temperature of 27 C (J. D. Zotter, personal communication).

N. ovalis grew at salinities from 8 to 81‰ but only survived in a medium with 4‰ salinity. Changes in the ionic ratios of major salts may promote growth in a medium with a salinity of 4‰ or in a fresh water medium. Paasche (1975) was unable to culture the fresh water diatom, *Skeletonema potamos* (C. Weber) Hasle (= *Microsiphona potamos*), in fresh water media, but got excellent growth in media from 2 to 24‰ salinity. He attributed this unexpected growth response to a particular ionic combination required by that diatom.

The growth rates of *N. ovalis* were reduced at the high and low salinities tested. Increased temperatures at the high and low salinities only slightly improved the growth rates.

A series of autecological studies were performed on a clone of *N. ovalis* isolated from the White Sea (Maksimowa and Vybornch 1967). Their isolate grew within a salinity range of 2 to 60‰ with an optimal range of 6 to 33‰. Peak growth occurred at 16‰ salinity. The optimal temperature range for the growth of their isolate was 19–22 C, and death occurred at 30 C. All cultures were exposed to a continuous illumination of 800 lux. Their peak growth falls within our optimal range of 16 to 36‰ salinity at 28 C, but the temperature results contrast markedly with ours and may indicate the existence of two thermal races. The existence of thermal races for phytoplankton species has been documented or suggested by Smayda (1958), Braarud (1962), Ignatiades and Smayda (1970), Hulburt and Guillard (1968), and Guillard and Ryther (1962). However, the lower light intensity might also result in death at 30 C because at this temperature or higher respiration rates could exceed photosynthetic rates at the cell's expense.

Despite the fact that the majority of the known field observations of *N. ovalis* did not include the temperature and salinity values or the cell density values at

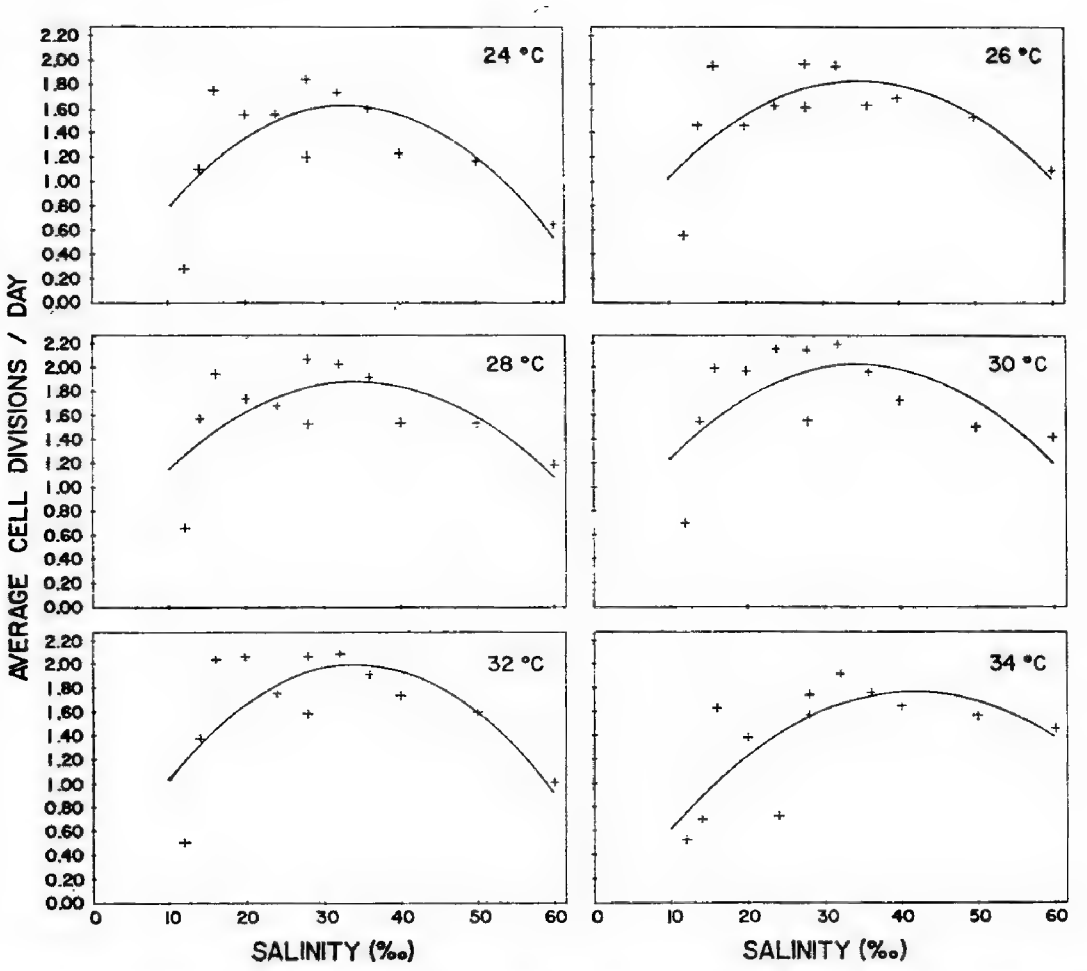

FIG. 2. The influence of temperature on the average cell divisions/day of *N. ovalis* grown at various salinities.

the time of the collections, it can be suggested from these experimental results that salinity and temperature responses of *N. ovalis* are fairly consistent with its known distribution. Although records exist only for the Atlantic and Arctic Oceans, the absence of this diatom from the Indian and Pacific Oceans may reflect uninvestigated areas. *N. ovalis* may be a cosmopolitan benthic species. It already meets the necessary prerequisites of being eurythermal and euryhaline, both of which are important environmental requirements for a ubiquitous neritic benthic distribution.

Comparisons of thermal tolerances between subtropical and arctic/temperate isolates of *N. ovalis* would open new areas of further study and might confirm the existence of physiological races within the taxon. Electrophoretic studies might detect genetic differences between the possible races.

ACKNOWLEDGMENTS

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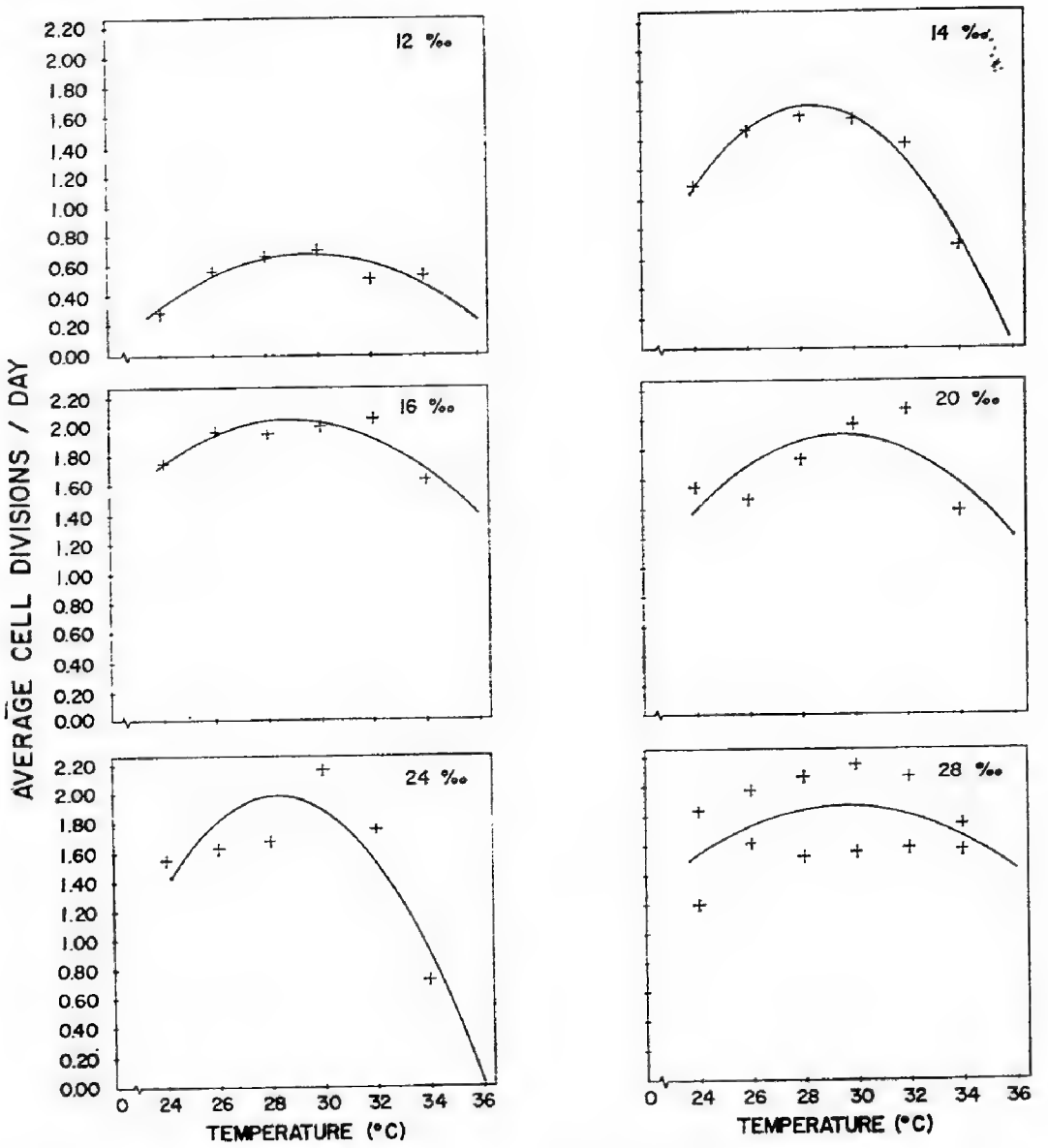

FIG. 3. The influence of salinity on the average cell divisions/day of *N. ovalis* growth at various temperatures.

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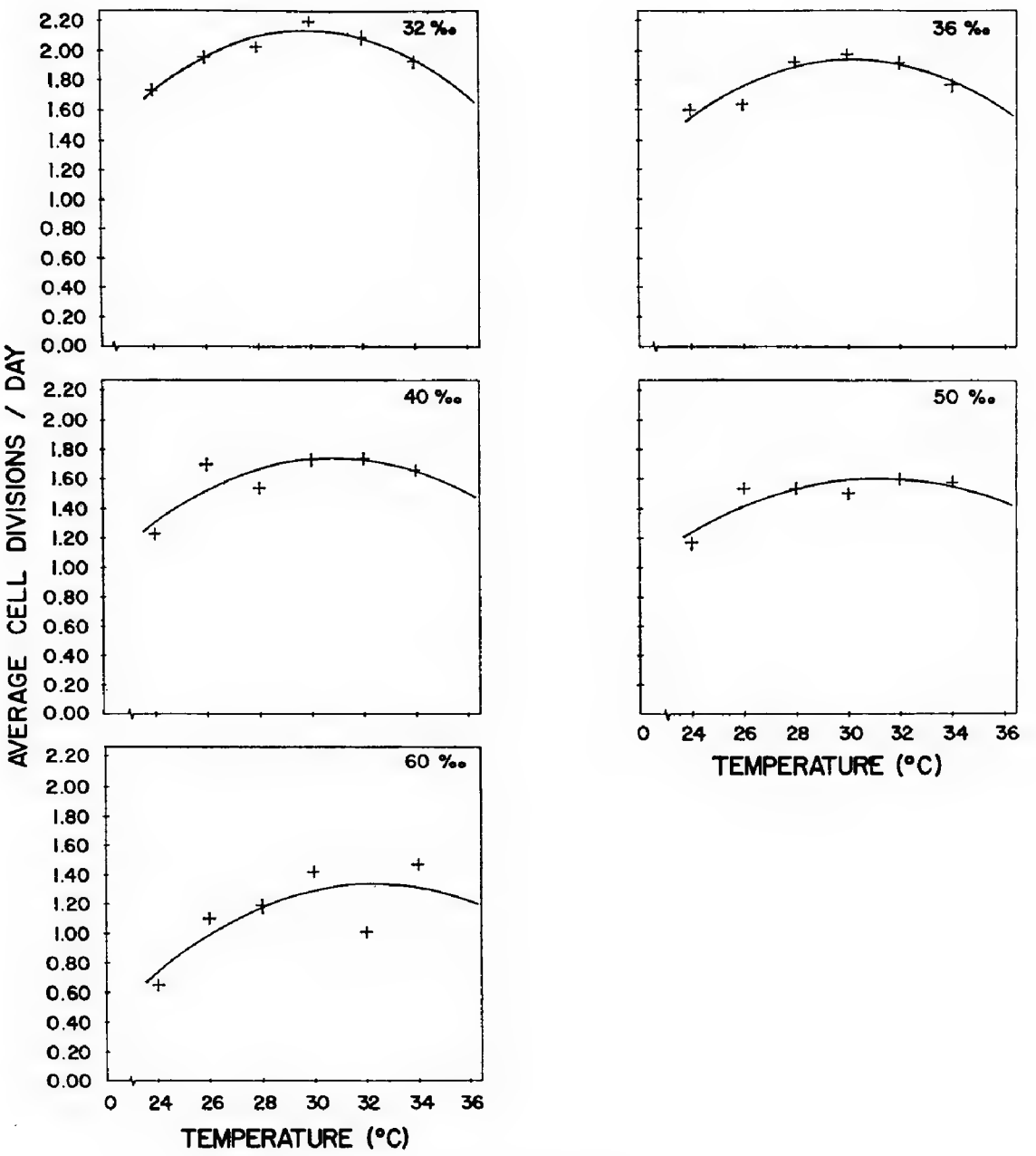

FIG. 3. Continued

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A SIMPLE MODEL OF THE SEASONAL GROWTH OF *SPARTINA ALTERNIFLORA* AND *SPARTINA PATENS*

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ABSTRACT

The seasonal growth of *Spartina alterniflora* and S. *patens* is shown to be closely related to the ambient potential evapotranspiration (PE) at the leaf surface. The relationship of log (live aboveground biomass) vs. log (air temperature) was found to vary within a marsh, but not among marshes on a marsh-average basis. The seasonal growth rate of *S. alterniflora* in all marshes appears to be linearly related to the seasonal changes in PE in the same manner that PE is related to temperature changes. A simple model describing the seasonal growth rates at any one location predicts *Spartina* sp. production from easily obtainable weather data, and provides some insight about the turnover rate of live material and seasonal nutrient availability.
Key words: *Spartina* sp., model, salt marsh, potential evaporation, temperature.

INTRODUCTION

Spartina alterniflora and *S. patens* are the dominant emergent macrophytes in many coastal salt marshes of the United States (Turner 1976). A causal relationship is presumed to exist between the productivity of these plants and the community energy flow and nutrient flux of the adjacent estuarine area (Teal 1962; Pomeroy, Shenton, Jones and Reimold 1972; Turner 1978). Several attempts have been made to model the seasonal growth rates of these plants at specific sites (Morgan 1961; Stroud and Cooper 1969; Waits 1967). The mathematical representations of seasonal growth derived from these studies were good for biological systems (coefficient of determination $[R^2] = 0.42 - 0.72$), but these efforts were oriented more toward describing growth *per se* than explaining growth as a function of the plant's genome and its interaction with the environment. The objective of this paper is to build a model of the seasonal growth of *Spartina* sp. that is generally applicable and also reflects knowledge of the plant's physiology, its environment, and the available growth data.

Plant Production and Transpiration

Spartina sp. are "C_4" plants; for such plants, the amount of water transpired is closely related to the amount of carbon fixed. In natural environments irradiance and temperature rarely reach values at which maximum photosynthetic

response is observed (Black 1971; Hatch, Osmund and Slatyer 1971).

An empirical relationship between plant production and plant transpiration has been established (Bouchet 1962, 1964; Damagnez 1968; Black 1971). Factors which influence this relationship include soil moisture levels, internal water deficits, humidity gradients and temperature. Abbe (1905), Robertson (1973), Viets (1962) and recent UNESCO symposia (1968, 1973) are useful references outlining the historical developments and current concepts on this subject. Of the four factors mentioned above, the seasonal changes in soil moisture and water deficit are probably not significant for *Spartina* sp. since the soil is nearly always saturated; Teal and Kanwisher (1970) showed that the leaf of *S. alterniflora* does not suffer from a water deficiency. The two other factors (humidity gradients and temperature) are closely related, of course. The vapor pressure gradient between the internal and external leaf environment is determined by the temperature at the point of evaporation and the ambient vapor pressure.

There are leaf stomata present in *Spartina* sp. but for three similar species there is a low resistance to CO_2 diffusion, suggesting that there is a low level of stomatal control of plant transpiration (Hesketh and Moss 1963). Both evapotranspiration energy and ambient vapor pressure are environmental factors determining a potential evapotranspiration (PE) rate which is independent of the plant. This potential depends on the available energy to evaporate water from a continuously wet surface; this point has been discussed more fully by Albrecht (1971). The leaf of *Spartina* sp. apparently is internally continuously wet and its temperature is nearly equal to air temperature (Teal and Kanwisher 1970); hence, we expect that the potential *environmental* moisture demand should be strongly related to plant transpiration. Air temperature can be related to PE and therefore leaf transpiration rates; hence environmental temperature changes should be related to changes in *Spartina* sp. production.

METHODS

Published data on *Spartina sp.* growth at various locations were analyzed. In many cases the actual sampling dates or absolute amounts of biomass were estimated from graphs; the coefficient of variation (within samples) was often greater than 25 percent. These factors introduced some error. The often-used harvest method of estimating seasonal productivity may underestimate the actual net aboveground production if leaf abscission or seasonal changes in the ratio of live to dead standing crop between sampling dates are not included in the estimate (Turner 1976). Corrections were not made for such estimations; thus live standing crop data were used as estimates of production. These estimates at different sites in a marsh were weighted in proportion to the relative area of each marsh type (as described in the original reference or companion research papers) to derive a marsh-average biomass. Plant transpiration was assumed to be closely related to the PE of a wet surface and was determined by the empirically-derived procedures described by Thornwaite and Mather (1957). The analysis used the 30-day average air temperature at the time of sampling obtained from records of the nearest weather station (U.S. Climatological Records).

RESULTS

All simple linear regression analyses reported here are significant at the 0.1 percent level. The monthly PE rate is a logarithmic function of the average

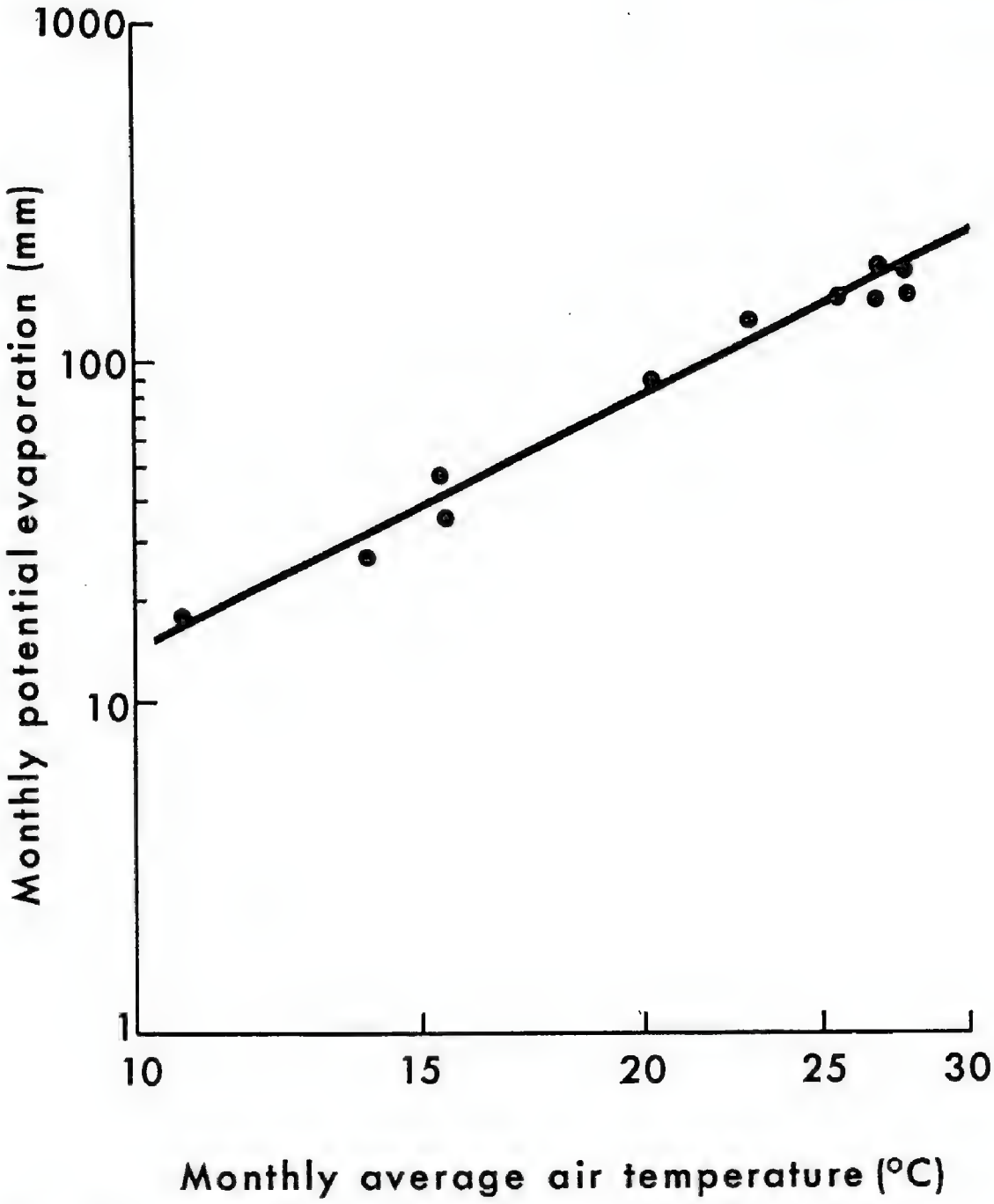

FIG. 1. The relationship between the monthly potential evapotranspiration rate and monthly temperature. The data were calculated using the instructions of Thornthwaite and Mather (1957) and are for Airplane Lake, Louisiana, 1971.

monthly air temperature for any one location (Fig. 1). During the growing season, the live aboveground standing crop of *Spartina* sp. (LAGS gm dry wt m^{-2}) was also found to be related to air temperature averaged for the previous 30 days (AGAT, Fig. 2); for any increase in temperature there is a predictable percent increase in biomass. At least 85 percent of the seasonal variation for most sites was statistically accounted for by this relationship (Table 1). For the only long-term data available, the slope of this regression changed slightly from one year to the next (Valiela and Teal 1974). The slope of the regression was different for experimental and control sites when nutrients were added twice monthly (Valiela and Teal 1974), but was not different when nutrients were added as treated sewage wastes over a long period of time (Marshall 1970). In both cases, the amount of biomass increased following the addition of nutrients.

The relationship between temperature and either PE or AGAT is not 1:1 (Fig. 3). That is, as the seasonal relationship between temperature and PE changes, the seasonal relationship between temperature and AGAT changes inversely. In essence, the more gradual the increase in PE (relative to temperature), the greater the increase in biomass (relative to temperature). Another way of looking at these data is presented in Figure 4. The relationship of cumulative growth during the "growing season" *vs.* cumulative potential evaporation was highly (statistically) significant for all sites. The R^2 of 0.93 for the example was typical.

DISCUSSION

The seasonal biomass of monotypic stands of *S. alterniflora* and of *S. patens* is shown to be strongly correlated with mean air temperature. This simple model has the attribute that determining the seasonal increases in biomass of *S. alterniflora* at any one location is simplified considerably with the use of readily accessible and simple weather data. In lieu of any other data, only a latitudinal average of biomass (e.g., in Turner 1976) or a one-time sampling is necessary to convert the slope of the biomass *vs.* temperature curve (derived from Fig. 3 and weather data) into an estimate of the absolute amount of biomass during any part of the growing season. It is possible to include both a decay constant for the fall decline in live biomass or even a second similar function describing understory growth which is initiated at this time. Within watershed differences in bio-

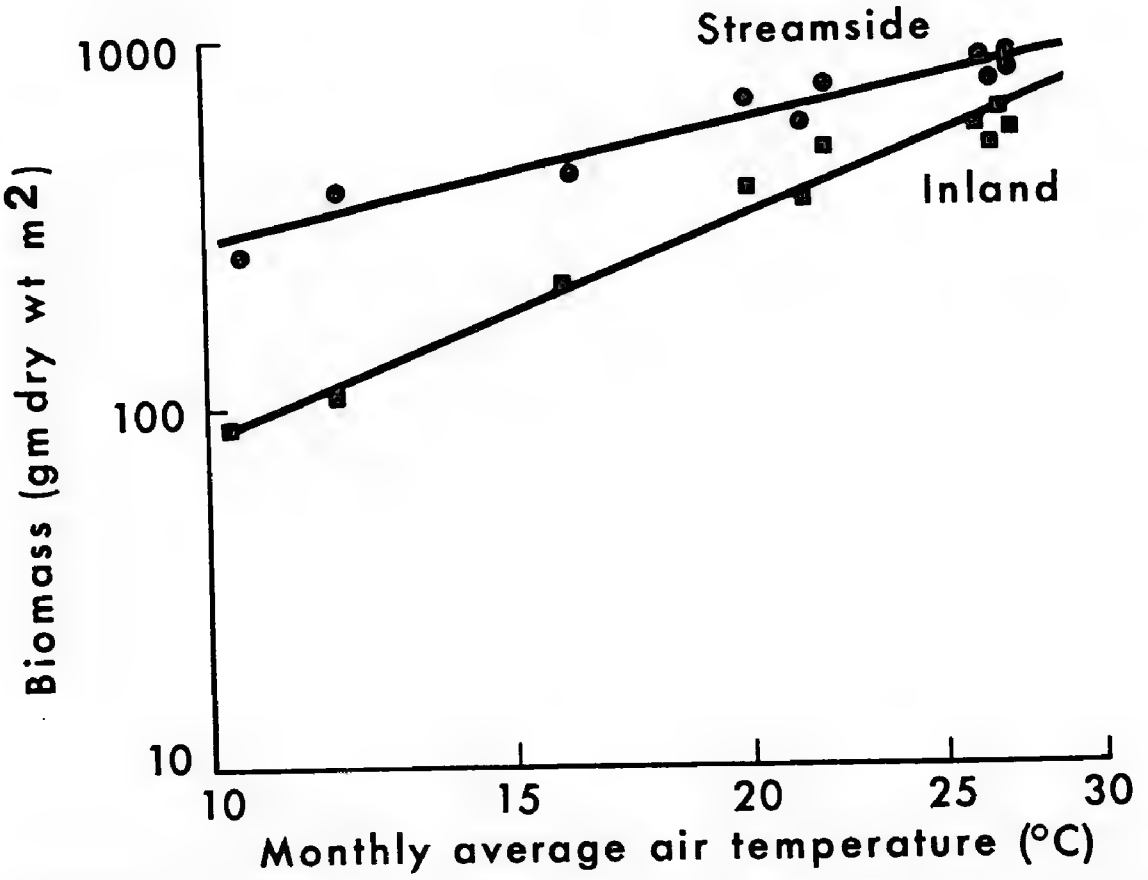

FIG. 2. The relationship between the live aboveground biomass of *Spartina alterniflora* and air temperature averaged for the preceding 30 days. The data for biomass were extracted from Kirby (1971) for Airplane Lake, Louisiana, and are for the period March to November 1971.

TABLE 1.

Coefficient of determination values (R^2) and slopes (b_1) for the relationship log (LAGS) = $b_1 + b_2$ log (AGAT) for *S. alterniflora* and *S. patens* (LAGS = live ground standing biomass; AGAT = average air temperature for the previous thirty days).

Location	Species	(n)	b_1	R^2	Source
1. Louisiana					
inland	*S. alterniflora*	(7)	1.30	.974[3]	Kirby 1971
streamside		(7)	2.06	.986[3]	
total study area		(7)	1.78		
2. Louisiana	*S. patens*	(9)	1.47	.80[3]	Payonk 1975
3. Georgia					
optimum site	*S. alterniflora*	(15)	1.78	.97[3]	E. P. Odum, pers. comm.
4. Georgia					
streamside levee	*S. alterniflora*	(7)	3.50	.97[3]	Smalley 1959
high	*S. alterniflora*	(8)	1.79	.89[3]	
marsh average			2.51		
5. North Carolina					
tall	*S. alterniflora*	(7)	1.40	.86	Williams and
medium	*S. alterniflora*	(7)	2.07	.96	Murdoch 1969
short	*S. alterniflora*	(7)	1.80	.92	
marsh average			1.72		
6. North Carolina					
control plots	*S. alterniflora*	(5)	1.42	.95	Marshall 1970
short	*S. alterniflora*	(5)	1.33	.96	
medium	*S. alterniflora*	(5)	1.31	.86	
tall	*S. alterniflora*		1.35		
numerical average					
7. North Carolina					
Site I, 1965	*S. patens*[2]	(8)	.87	.97[3]	Waits 1967
Site I, 1966	*S. patens*[1]	(8)	1.12	.97[3]	
Site I, 1966	*S. patens*[2]	(8)	.50	.73[3]	
	S. patens[1]	(8)	.60	.72[3]	
Site II, 1965	*S. patens*[2]	(8)	.79	.91[3]	
	S. patens[1]	(8)	1.20	.91[3]	
Site II, 1966	*S. patens*[2]	(6)	.79	.72[3]	
	S. patens[1]	(6)	.69	.96[3]	
Site IV, 1965	*S. patens*[2]	(8)	.64	.91[3]	
	S. patens[1]	(8)	.99	.73[3]	
Site IV, 1966	*S. patens*[2]	(5)	.79	.72[3]	
	S. patens[1]	(5)	.69	.96[3]	
Average					
1965 (all monotypic stands)			.98		
1966 (all monotypic stands)			.66		
8. North Carolina					
short	*S. alterniflora*	(8)	1.92	.97[3]	Stroud and
medium	*S. alterniflora*	(8)	1.66	.91[3]	Cooper 1969
average			1.78		
9. Maryland	*S. patens*[2]	(7)	1.98	.72[3]	Cahoon 1975
	S. alterniflora[2]	(7)	3.64	.87[3]	
10. Delaware	*S. alterniflora*[2]	(7)	4.33	.97[3]	Morgan 1961
	S. alterniflora[1]	(6)	3.99	.96[3]	
11. New Jersey					
tall-intermed.	*S. alterniflora*	(5)	2.56	.93	Squiers and
short	*S. alterniflora*	(4)	1.95	.82	Good 1974
average	*S. alterniflora*		2.25		
12. Connecticut					
tall	*S. alterniflora*	(6)	2.56	.86[3]	Steever 1972
short	*S. alterniflora*	(3)	4.2	.98[3]	
average	*S. alterniflora*		3.43		
	S. patens	(5)	2.88	.98	
13. Massachusetts					
control 1972					
low	*S. alterniflora*	(5)	2.05	.73	Valiela and Teal
high	*S. alterniflora*	(5)	3.40	.88	1974
average	*S. alterniflora*		2.72		
nitrogen added 1972					
low	*S. alterniflora*		3.03	.93	
high	*S. alterniflora*	(5)	2.91	.86	
phosphorus added 1972					
low	*S. alterniflora*	(5)	2.15	.87	
high	*S. alterniflora*	(5)	2.59	.93	
14. Canada					
tall	*S. alterniflora*	(5)	2.8	.999	Hatcher and Mann
medium	*S. alterniflora*	(5)	7.0	.986	1975
short	*S. alterniflora*	(5)	.94	.988	
numerical average			3.6		

[1]almost a pure stand
[2]mixed community with the dominant as stated
[3]raw data for sampling dates and biomass harvested was available

mass growth, though not treated in this model thus far, can be partially accounted for by including the empirical relationship shown in Figure 5 into a model. It shows that the ratio of inland/streamside end-of-season live biomass is indirectly proportional to the tidal amplitude in the estuary (for *Spartina alterniflora* only). The ratio approximates the relative production of the whole marsh at subsites within the marsh. Generally, however, the modelling approach used here is most useful at the regional rather than microhabit level.

Maximum accumulation of live material is achieved at the temperature maximum in late summer rather than at the light maximum in June. Bull (1971) has pointed out that the high annual growth of C_4 plants is largely associated with this extended growing season. This is apparently the case for *Spartina* sp. and at least two other C_4 emergent macrophytes, *Miscanthus sacchariflorous* and *Distichlis spicata* (Downton 1971; Mutah, Yosida, Yokoi, Kimura and Hogetsu 1968) whose relative growth rates are similarly related to temperature.

The environmental temperatures encountered by *Spartina* sp. are apparently not inhibitory to growth. Water is in constant supply, thus it is not surprising that an estimate of PE is closely related to the actual plant evapotranspiration, hence net growth. Rosenzweig (1968) for example, described the annual net production of numerous mature ecosystems (ranging from tundra to rain for-

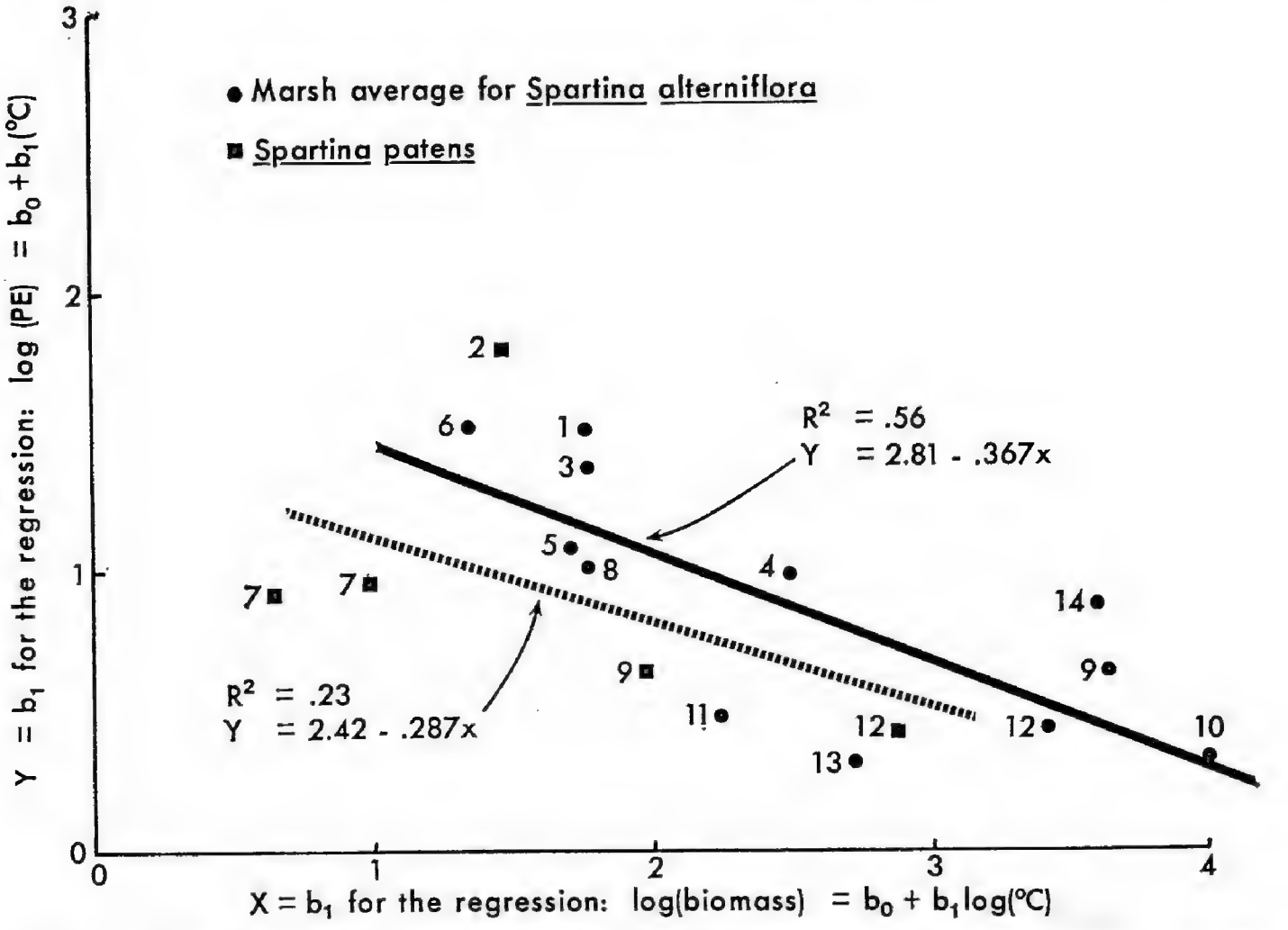
● Marsh average for Spartina alterniflora
■ Spartina patens
R² = .56
Y = 2.81 - .367x
R² = .23
Y = 2.42 - .287x
Y = b1 for the regression: log (PE) = b0 + b1(°C)
X = b1 for the regression: log(biomass) = b0 + b1log(°C)
0
1
2
3
4

FIG. 3. The relationship between the slope of the regression, monthly potential evaporation $= b_0 + b_1$ log °C, and the slope of the regression, log (live biomass *Spartina alterniflora*) $= b_0 + b_1$ (AGAT) for the data in Table 1.

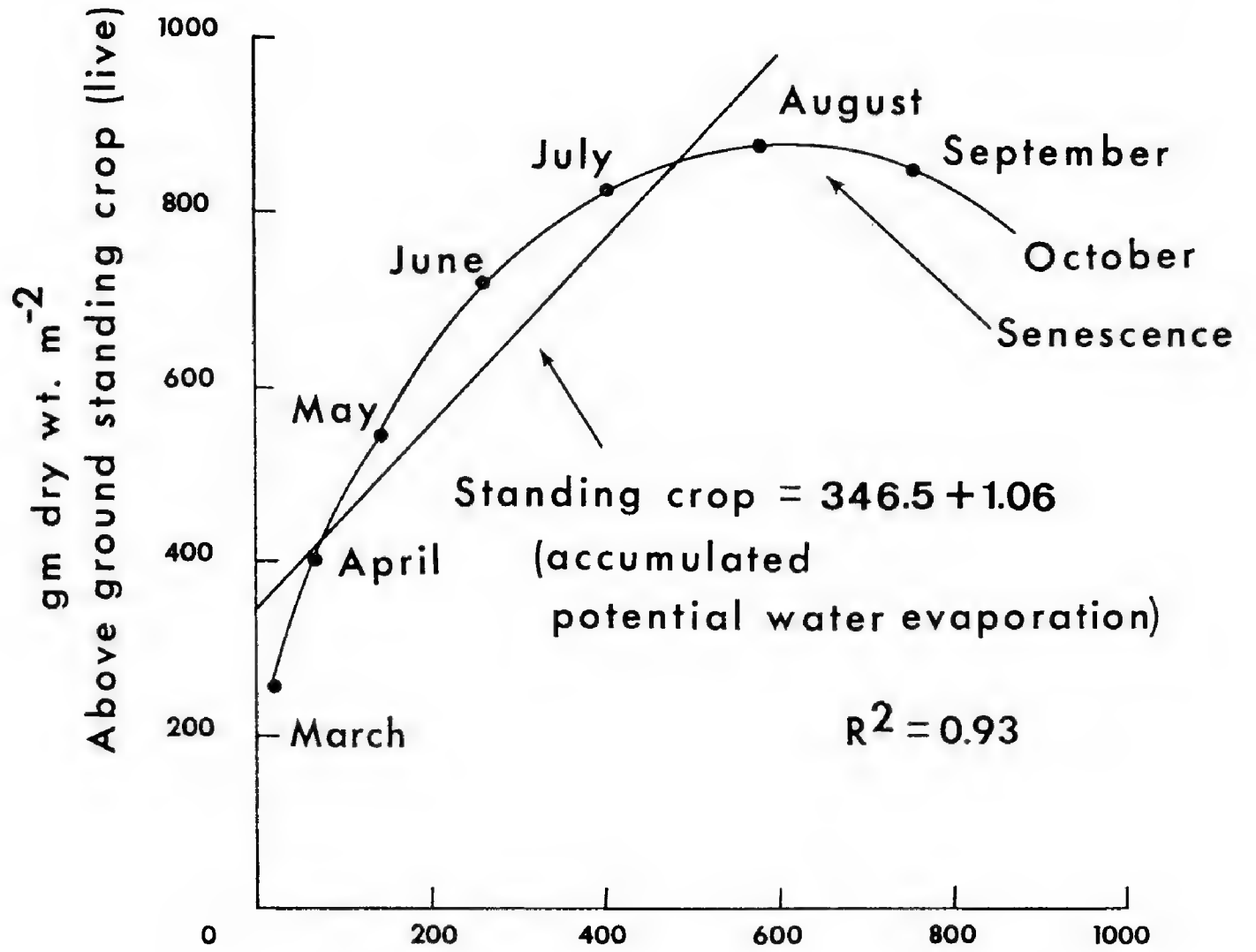

FIG. 4. The relationship between the live standing crop of *Spartina alterniflora* (streamside location at Airplane Lake, Louisiana [Kirby 1971]) and the accumulated potential water evaporation since January. The regression is for the period March through August, 1971.

est) as a function of the actual evapotranspiration. It should be expected then, that the linear standing crop (live) *vs.* air temperature is a log:log relationship, as is the relationship between monthly potential evapotranspiration and air temperature.

The relationship of the data in Figure 3 seems to suggest that the more gradual the change in temperature, the greater the change in production (relative to temperature). These curves are relative; they do not suggest anything about absolute growth. They do support the hypothesis that if nutrients are limiting, nutrients limit growth in a similar manner in all marshes. Within a marsh, however, the relationship of biomass *vs.* temperature at streamside sites compared to biomass *vs.* temperature at more interior marsh areas varied in an inconsistent manner with both latitude and absolute production. Additionally, the strong relationship between the seasonal changes in average biomass and temperature for all locations suggests that any turnover of live material during the growing season (turnover is not included in the harvest method) is related to changes in temperature in the same manner as is standing crop or, alterna-

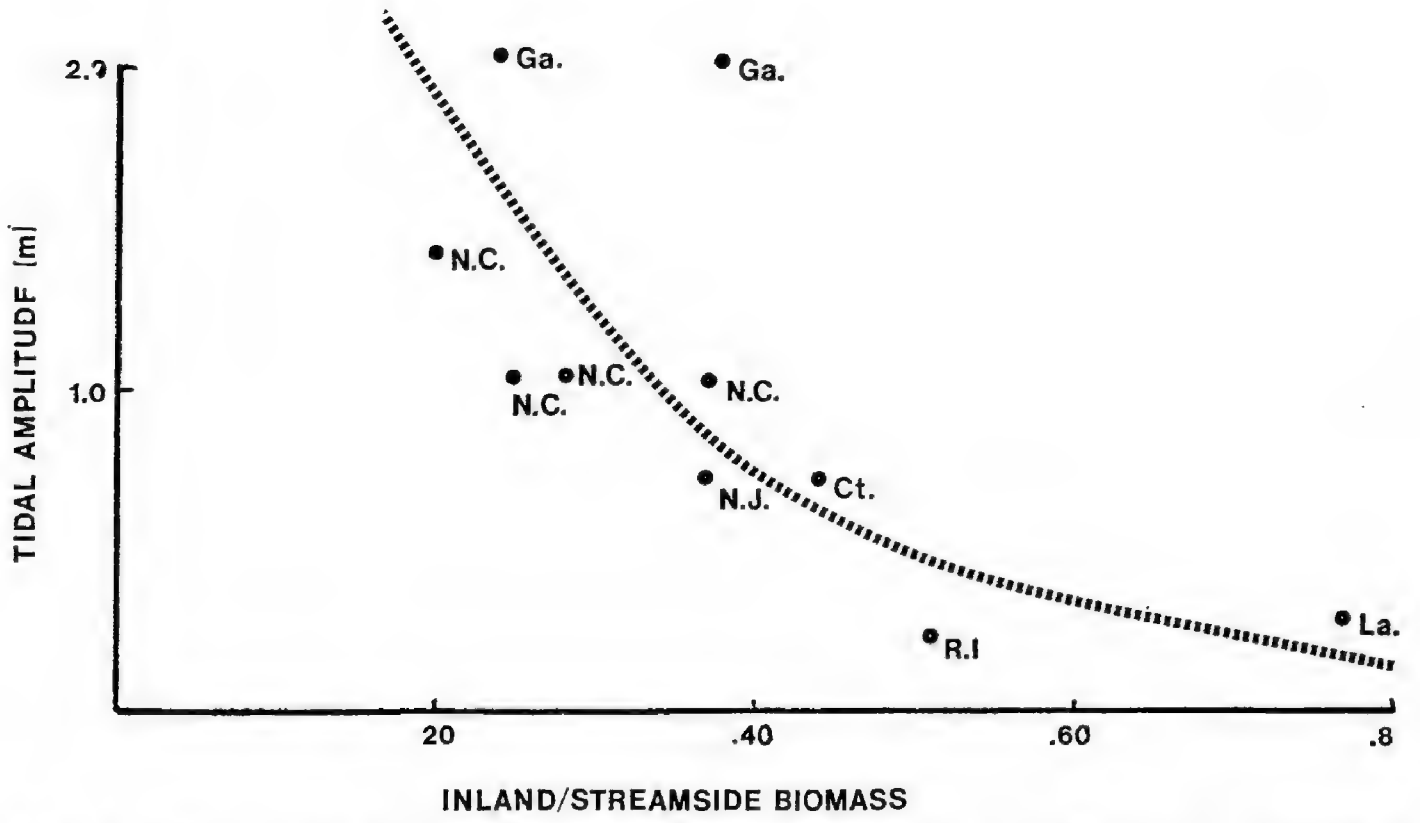

FIG. 5. The relationship between tidal amplitude and live end-of-the-season biomass at streamside and inland locations (the data are from Table 1 of Turner, 1976).

tively, that turnover of live material is nearly constant (g turnover/g live material/day) (e.g. Hopkinson, Gosselink and Parrondo 1979; Reimold, Gallagher, Linthurst and Pfeiffer 1975). Because of the longer growing season, plants in the more southerly latitudes would have a higher annual turnover per area (Turner 1976).

The strong correlation between temperature and plant growth also suggests that if total growth is nitrogen limited (e.g. Valiela and Teal 1974; Hanson 1977) then the relative availability of nitrogen for growth throughout the growing season is nearly constant. Much of the nitrogen required by the plant is suspected to come from the rhizosphere (Mann 1972; Hanson 1977). Dissolved organic matter released from the root serves as a substrate and electron donor for a nitrogen-fixing reaction by symbionts, which in turn supplies some nitrogen to the plant. Is seems possible that this exchange, driven by dissolved organic matter released by the plant, is in turn coupled to transpiration. Flushing and chemical characteristics of the soil-water system would influence the efficiency and magnitude of this exchange process, but these characteristics would be seasonally constant.

The eventual decline of the overstory as temperature drops in the late summer probably results from a combination of diminishing nutrient reserves, leakages of material during tidal submergence, concurrent decreases in temperature and light, and perhaps a physiological "cue." Light and temperature then are still adequate for the chemical process of photosynthesis to occur for a net gain in carbon fixation (Young 1974), but the maintenance energy available for the existing biomass is apparently not sufficient for photosynthesis to proceed for a net gain in biomass. At this point, senescence sets in and the standing biomass

of live material starts to decrease. El-Sharkaway and Hasketh (1964) and Moss, Musgrave and Lemon (1961) have suggested that growth and senescence are controlled by a temperature-mediated response of respiration. In *Spartina* sp. it seems that growth m^{-2} is not directly controlled by temperature effects on respiration although senescence may be.

In conclusion, the model is simple, determined from easily obtainable weather data and is applicable over the wide geographic range where these plants are found; it fits into a theoretical framework based on knowledge of the plant's physiology and its environment; it provides some interesting insights about the variation in *Spartina* sp. growth over a wide area. Since many computer-simulated ecosystem models of saltmarsh ecosystems include a "submodel" of seasonal variations in temperature, this proposed approach can be easily incorporated into the larger model.

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DISTRIBUTION, ABUNDANCE, FEEDING AND LONG-TERM FLUCTUATIONS OF SPOT, *LEIOSTOMUS XANTHURUS*, AND CROAKER, *MICROPOGONIAS UNDULATUS*, IN APALACHICOLA BAY, FLORIDA, 1972–1977[1]

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ABSTRACT

Seasonal distribution, abundance and trophic functions of *Leiostomus xanthurus* and *Micropogonias undulatus* were studied at a series of stations in Apalachicola Bay, Florida. Highest catch/effort of spot was found in upper East Bay and East Bay. Apalachicola Bay and East Bay yielded the greatest catch/effort of croaker. Abundance of the two species peaked in the spring and declined in the fall. Stomach contents showed croaker and spot are primarily omnivorous. Principal foods of spot included polychaetes, harpacticoid copepods, detritus and bivalves. Croaker consumed primarily polychaetes and detritus. Comparison of diets of croaker and spot revealed high intraspecific similarity on a size class basis and high interspecific similarity on an areal basis.

Population fluctuations and spatial distribution of croaker and spot were studied as a response to a number of environmental and trophic factors. Presence or absence of benthic macrophytes, salinity, color and turbidity, bottom type and food availability determined the long-term spatial distribution of the two fishes. Temperature is a critical parameter for at least one of these species while variations in rainfall and river flow have little effect on either population.

INTRODUCTION

Croaker, *Micropogonias undulatus*, and spot, *Leiostomus xanthurus*, are two of the dominant fishes in Apalachicola Bay and other estuaries of the Southeastern United States. The life history of these fishes has been previously studied (Pearson 1929; Dawson 1958; Haven 1959; Bearden 1964). Few studies, however, involve qualitative and quantitative sampling over long periods of time. Knowledge of seasonal distribution and trophic structure in conjunction with

[1] EDITORIAL FOOTNOTE: Several recent authors use the more appropriate generic name *Micropogonias* instead of the familiar *Micropogon*; Chao and Musick (1977), White and Chittenden (1977), and Richard M. Moore (in review).

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long-term monitoring of populations is useful in predicting any man-induced or natural changes. The purposes of this study are to (1) describe seasonal distribution, abundance and feeding patterns of spot and croaker from Apalachicola Bay, Florida and (2) relate long-term population fluctuations with environmental factors and biological functions.

MATERIALS AND METHODS

Biological and physicochemical samples were collected monthly on stations in the Apalachicola Bay system (Figure 1) from April, 1972 to June, 1977. Salinity, temperature, dissolved oxygen, secchi disk, depth, color and turbidity readings were taken at the surface and bottom of each station. River flow data were obtained from the U.S. Army Corps of Engineers at Mobile, Alabama. Local rainfall data were recorded at Apalachicola and East Bay (Tate's Hell Swamp). Daily temperature and degree day data were supplied by the National Weather Service at Apalachicola, Florida. A more detailed account of the sampling methodology was described in Livingston *et al.* (1976).

Specimens were collected with a 5m (16-foot) otter trawl, 19 mm (¾-inch) mesh wing and body, 6mm (¼-inch) mesh liner, towed for 2 minutes at a speed of 2–3 knots. Seven replicate tows were made on stations 1, 5, 6, 4A, 5B, and 5C, while two replicates were made on all the other stations. Organisms were preserved at 10% formalin, identified and measured (standard length). Stomach analyses were performed on fishes collected from January through November, 1976. Stomachs of up to 25 individuals from each size class (10–19 mm, 20–29mm, etc.) were resected and their pooled contents stored in 40% isopropanol. Contents were then analyzed as percent dry weight composition by a gravimetric procedure described by Carr and Adams (1972, 1973). Statistical analysis of stomach data was conducted utilizing the ρ index of affinity (Matusita 1955; VanBelle and Ahmad 1974) coupled with flexible group cluster analysis (Lance and Williams 1967).

RESULTS

Physicochemical Parameters

Apalachicola Bay is a shallow, relatively unpolluted estuary enclosed by barrier islands and dominated physically by the Apalachicola River. Maximal river flow usually occurs during January–April of each year. Minimal flow is during the late summer and fall. Local rainfall did not coincide with river flow, usually peaking during summer and early fall. River flow showed considerable annual variation, flooding in 1973, with low levels in 1972, 1976 and 1977. The Apalachicola River was the primary determinant of salinity regimes within the bay, while salinity fluctuations during summer and fall in East Bay were due to local rainfall and runoff. In general, salinity and water temperature decreased over the study time, with extremely low temperatures recorded during the winter of 1977. No vertical or horizontal stratification of water temperature was found (Livingston *et al.* 1976). Turbidity values were high and directly related to river flow. Color was related to river flow and rainfall. Although Apalachicola Bay is a complex interaction of various physical and chemical parameters, river flow apparently dominates this system (Livingston *et al.* 1976).

Distribution, Abundance, and Feeding of *Micropogonias*

Micropogonias is one of the dominant fishes of the coastal waters of the northern Gulf of Mexico (Gunter 1945; Perret and Caillouet 1974; Livingston

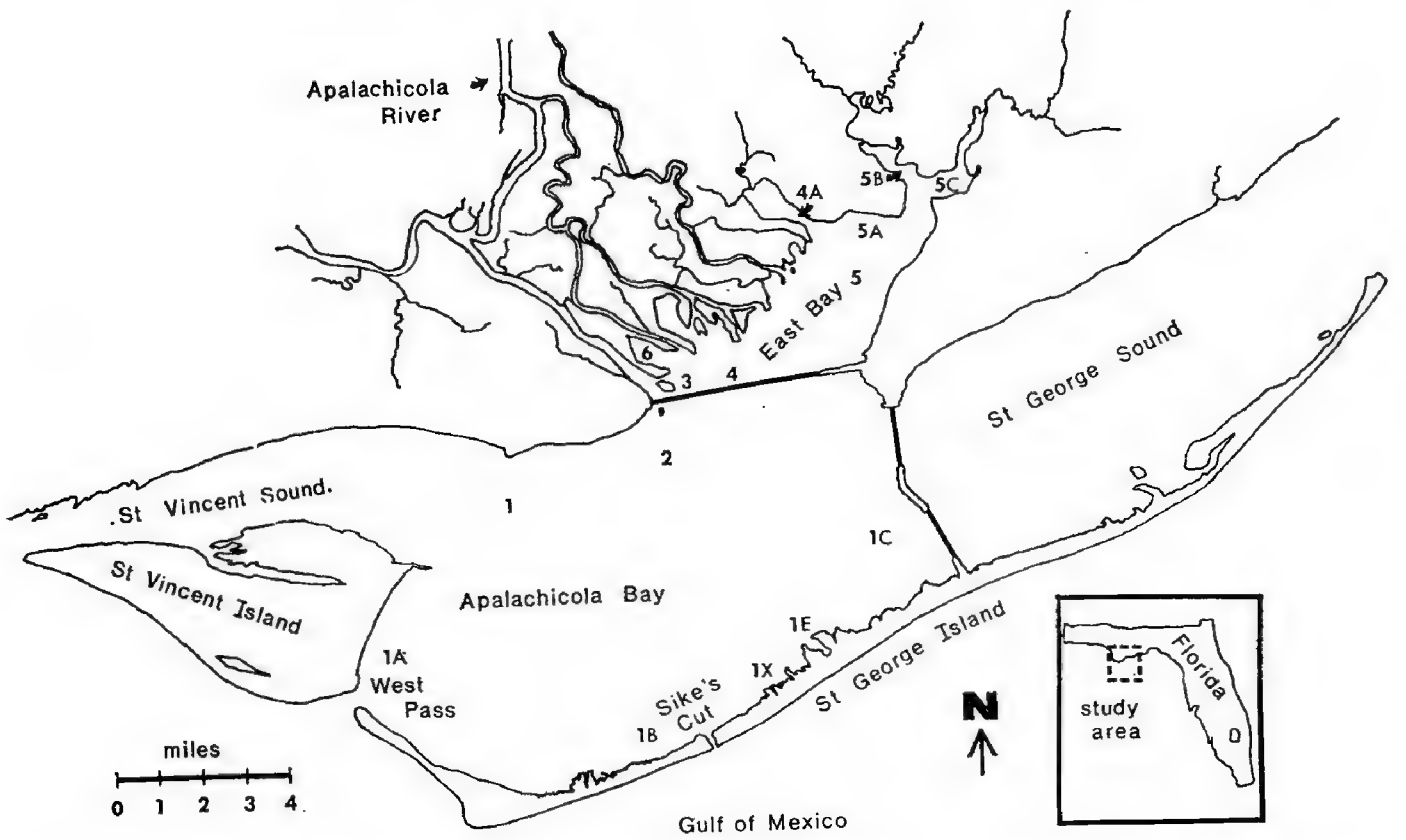

FIG. 1. The Apalachicola Bay System with long-term sampling stations (1, 1A, 1B, 1C, 1E, 1X, 2, 3, 4, 4A, 5, 5A, 5B, 5C, 6).

et al. 1976). Spawning occurs near the passes and channels to the Gulf (Pearson 1929). Juveniles have been reported in estuaries from October to April (Gunter 1945; Perret 1971) with peak abundance in spring and summer (Fox and Mock 1968; Perret and Caillouet 1974). The croaker was the second most abundant fish in Apalachicola Bay, comprising 27.9% of the total catch. Juvenile croakers were initially taken in the Apalachicola estuary in November with peak abundance during January–April of each year. A decline in numbers during June and July was probably the result of natural mortality, a gulfward migration, and increased net avoidance by larger fish. Pearson (1929), Haven (1959) and Perret (1971) report a similar decrease in catch in the fall.

Catch/effort (C/E) of croaker from Apalachicola Bay (Stations 1, 1A, 1B, 1C, 2), East Bay (3, 4, 5, 5A, 6), upper East Bay (4A, 5B, 5C) and St. George Island (1E and 1X) is shown in Table 1. Highest catch/effort was found at Station 2, a maintained ship channel at the outflow of the Apalachicola River into the bay. The capture of 1244 individuals in 2 tows in April 1976, however, accounts for the 139.6 C/E for 1976 and subsequently high 5 year average. In general, East Bay and Apalachicola stations 1, 1C and 2 attracted the greatest concentrations of croakers. These areas were shallow (1–2m), of low salinity (avg. 9.6 ppt), with soft mud and large quantities of detritus. *Micropogonias* was noticeably absent from the higher salinity (avg. 19.2 ppt) grass bed stations (1X and 1E) adjacent to St. George Island. Few croaker were collected at higher salinity (avg. 25.3 ppt) mud and sand bottom locations near West Pass (1A) and Bob Sikes Cut (1B). Considerable year to year variation was found in all of the study areas, with peak abundance in 1973 and 1976.

TABLE 1

Catch/effort during 1973–1977 of *Micropogonias undulatus* (A) and *Leiostomus xanthurus* (B) on 15 stations in four sampling regions: Apalachicola Bay (AB), East Bay (EB), Upper East Bay (UE), and St. George Island (SG).

A. *MICROPOGONIAS UNDALATUS*

	1	1A	1B	1C	2	AVG. AB	3	4	5	5A	6	AVG. EB	4A	5B	5C	AVG. UE	1E	1X	AVG. SG
1973	29.7	6.9	1.0	38.2	13.1	17.8	2.8	28.9	25.6	27.0	52.9	27.4							
1974	23.4	1.1	1.9	16.4	26.3	13.8	5.3	24.5	18.2	21.7	42.9	22.5							
1975	15.8	5.9	1.1	22.4	14.9	12.0	3.3	56.4	21.1	21.2	7.4	21.9	12.4	9.4	34.9	18.9	.9	0	.5
1976	26.8	12.0	1.4	42.3	139.6	44.4	20.4	73.7	43.7	44.5	26.8	41.8	17.4	23.3	26.6	22.4	1.1	.1	.6
1977	18.5	2.1	.3	26.5	45.6	18.6	6.9	22.0	21.8	12.5	12.9	15.2	9.6	10.5	13.7	11.3	.1	1.6	.9
AVG.	22.8	5.6	1.1	29.2	47.9	21.3	7.7	41.1	26.1	25.4	28.6	25.8	13.1	14.4	25.1	17.5	.7	.6	.7

B. *LEIOSTOMUS XANTHURUS*

	1	1A	1B	1C	2	AVG. AB	3	4	5	5A	6	AVG. EB	4A	5B	5C	AVG. UE	1E	1X	AVG. SG
1973	1.8	.4	2.1	8.6	9.6	4.5	.4	5.0	3.9	12.4	9.6	6.3							
1974	.3	.1	0	.7	2.0	.6	.1	7.3	.5	2.2	10.8	4.2							
1975	2.0	1.1	1.4	6.6	1.6	2.5	5.3	13.7	10.8	34.7	15.5	16.0	32.1	26.5	56.3	38.3	36.4	1.8	19.1
1976	3.4	6.2	2.1	7.4	4.4	4.7	47.5	4.6	39.3	144.5	24.5	52.1	85.4	80.5	50.8	74.1	60.5	5.3	32.9
1977	21.0	5.6	2.8	6.2	3.4	7.8	52.2	42.5	88.4	112.8	68.7	72.9	103.5	67.1	139.6	103.4	120.8	27.4	74.1
AVG.	5.7	2.7	1.7	5.9	4.2	4.0	21.1	14.6	28.6	61.3	25.8	30.3	73.6	58.0	82.3	71.9	72.6	11.5	42.0

A total of 2215 *M. undulatus* stomachs were examined, forming 165 station-date-size class combinations. Generalized stomach content data are summarized by size class, over all stations and dates, in Table 2. In the Apalachicola Bay estuary, polychaetes form the basis of the croaker diet, averaging 32.4% by weight for all size classes (10–159 mm). Relatively large amounts of detrital matter were also ingested (avg. 15.9%).

Cluster analysis of stomach contents for *M. undulatus* show two distinct size class feeding types (Figure 2): (1) an intense cluster of 10–69 mm fish whose diet included greater than 50% polychaetes, insect larvae and detritus; and (2) a loose grouping of 70–159 mm fish whose diet included mainly polychaetes, infaunal shrimp, crabs and/or juvenile fishes, usually with one or two of these items comprising 50–85% by weight. Interstation similarity analysis (Figure 3) demonstrated 3 station groups: (1) Stations 3, 5, 5A and 6, utilized by 10–79 mm fish, mainly March through May and characterized by large amounts of insect larvae, detritus and a variety of small crustaceans; (2) Stations 1, 1A, 1C and 4, utilized by most size classes during the study, with feeding predominated by polychaetes and lesser amounts of shrimp and juvenile fishes; and (3) Stations 2 and 1B, also used by most size classes during the study, with polychaetes but a minor component and feeding characterized by mysids, shrimp and fish.

Distribution, Abundance and Feeding of *Leiostomus*

Leiostomus is relatively abundant in the northern Gulf of Mexico. This fish is dominant in Tampa Bay (Springer and Woodburn 1960) and Alligator Harbor (Joseph and Yerger 1956) and is common in the coastal waters of Alabama (Swingle and Bland 1974), Louisiana (Perret and Caillouet 1974) and Texas (Gunter 1945). In Apalachicola Bay, spot accounted for 11.1% of the total fishes collected. Appearance of juveniles in the fall and peak abundance during January–May coincided with that of *M. undulatus*. Lowest catches of spot were made in the summer and fall. Apparently spot migrate from the bays to the Gulf during this time (Pearson 1929; Gunter 1945).

Catch/effort of spot from Apalachicola Bay, East Bay, upper East Bay and St. George Island is shown in Table 1. Highest catch/effort was found at two locations—the low salinity, high turbidity and color, mud bottom locations near upper East Bay marshes (4A, 5B and 5C) and the high salinity, low turbidity and color, grassbed station (1E) adjacent to marshes on St. George Island. In addition, considerable number of spot were collected in the East Bay area. Few *Leiostomus* were found at Apalachicola Bay stations. All locations exhibited considerable annual variation, with low numbers found in 1973 and 1974 and high catches in 1976 and 1977.

A total of 903 *L. xanthurus* stomachs were examined, forming 81 station-date-size class combinations. Generalized stomach content data are summarized by size class, over all stations and dates, in Table 3. On the average, spot do not depend heavily upon one or two main food sources. Polychaetes (23.8%), harpacticoid copepods (21.0%), detritus (16.3%) and bivalves (10.4%) are the major food organisms.

TABLE 2.

Stomach contents (as % of total dry weight) of *Micropogonias undulatus* by size class, summed over all stations and sampling dates.

Food Item	Size (mm) 10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	150-159	Avg. 10-159
Sand grains		<.1			<.1	0.2	0.2		0.3	<.1	2.1			0.2
Sediment masses			0.2	2.4	1.5	3.3	3.3	8.2						2.2
Detritus	7.1	6.5	12.9	19.4	17.5	19.2	19.0	15.0	19.5	10.3	6.8	14.1	9.7	15.9
Plant remains		<.1	0.3	0.4	<.1	0.4	0.1	<.1	0.6	0.7	<.1		0.3	0.2
Nematodes	0.8	0.4	<.1	<.1	<.1	<.1	<.1				2.1			0.2
Polychaetes - larval		<.1	<.1											<.1
- juv./adult	26.2	31.5	35.6	36.6	29.6	31.7	28.1	48.4	54.7	32.8	4.4	40.1	34.0	32.4
Gastropods				.1	<.1	0.3								<.1
Bivalve siphons			1.5	2.8	3.7	3.1	3.0	1.2	3.2					2.2
Bivalves	0.8	1.0	0.9	0.6	0.1	0.3	0.1							0.3
Cladocerans		<.1	<.1	<.1		<.1								<.1
Ostracods	0.2	0.2	<.1	<.1		<.1	<.1							<.1
Calanoid copepods	10.0	7.1	4.2	6.0	9.1	7.8	7.1	1.6	2.1	<.1	0.1			5.7
Harpacticoid copepods	12.2	8.6	2.7	1.9	4.3	2.4	0.7	0.1			<.1			2.3
Cumaceans	1.4	0.6	0.4	0.2	0.1	<.1	<.1	<.1						0.2
Isopods			0.2	0.7	3.6	2.9	0.9	0.1						1.4
Amphipods	5.3	16.9	13.6	6.8	3.7	4.6	3.8	2.3	0.3	0.1	1.8	0.2		5.5
Mysids	8.0	5.7	5.0	8.2	10.4	11.3	11.0	2.3	5.6		2.7	2.2		7.4
Shrimp - postlarval			<.1		<.1									<.1
- juv./adult		0.1	1.4	0.9	2.9	4.8	10.3	10.1	2.1	1.8	46.0	43.3	10.9	6.8
Crabs					0.8	0.6	0.4			0.5			45.1	0.7
Unassigned decapod larvae				<.1										<.1
Insect larvae	27.9	20.9	20.8	11.6	11.9	5.0	0.5	0.2			1.2			8.2
Ophiuroids							1.0							<.1
Unassigned invert. eggs	0.1		<.1		<.1		<.1	<.1						<.1
Fish - eggs				<.1	<.1									<.1
- larvae		0.3	0.3	1.2										0.2
- juvenile					0.5	0.8	10.3	10.4	1.8	53.7	32.7			8.2
- bones, scales				<.1		1.2								<.1

Cluster analysis of stomach contents for *L. xanthurus* showed three size-related feeding categories (Figure 2): 20–69 mm fish whose diet was dominated by insect larvae, harpacticoid copepods, and detritus; (2) 70–99 mm fish whose diet included mainly detritus, harpacticoid copepods and polychaetes; and (3) 100–109 mm fish whose main food was bivalves. Interstation similarity analysis (Figure 3) demonstrated 2 clusters; (1) stations 3, 5, 5A and 6, utilized by all size classes during most sampling months and characterized by consumption of bivalves, insect larvae and detritus; and (2) stations 1, 1A 1B, 1C, and 4, utilized only through June by a variety of size classes and characterized by predation upon polychaetes and harpacticoid copepods.

DISCUSSION

Areal Abundance of *Micropogonias* and *Leiostomus*

Although croaker were considerably more numerous than spot in most collections from Texas, Alabama, Louisiana and Florida, differences in the abundance of the two species have been noted in certain habitats. Parker (1971) collected more *Leiostomus* in the high salinity waters of Lake Borgne, Louisiana, and found *Micropogonias* dominant in low salinity Galveston Bay, Texas. Swingle and Bland (1974) found spot more abundant than croaker at high salinity stations in coastal Alabama waters. Croaker are reported scarce or absent from shallow areas east of Alligator Harbor, Florida, a region characterized by dense benthic macrophyte assemblages and low turbidity waters (Reid 1954; Livingston 1975). In addition, *Micropogonias* are noticeably absent from marsh collections on the Gulf Coast, while *Leiostomus* are frequently encountered (Kilby 1955; Arnoldi *et al.* 1973). In the Apalachicola Bay System, spot were more abundant than croaker in the high salinity marsh station (1E) near St. George Island and the low salinity stations (4A, 5B, 5C) near upper East Bay marshes. More croaker were collected in Apalachicola Bay, while both species

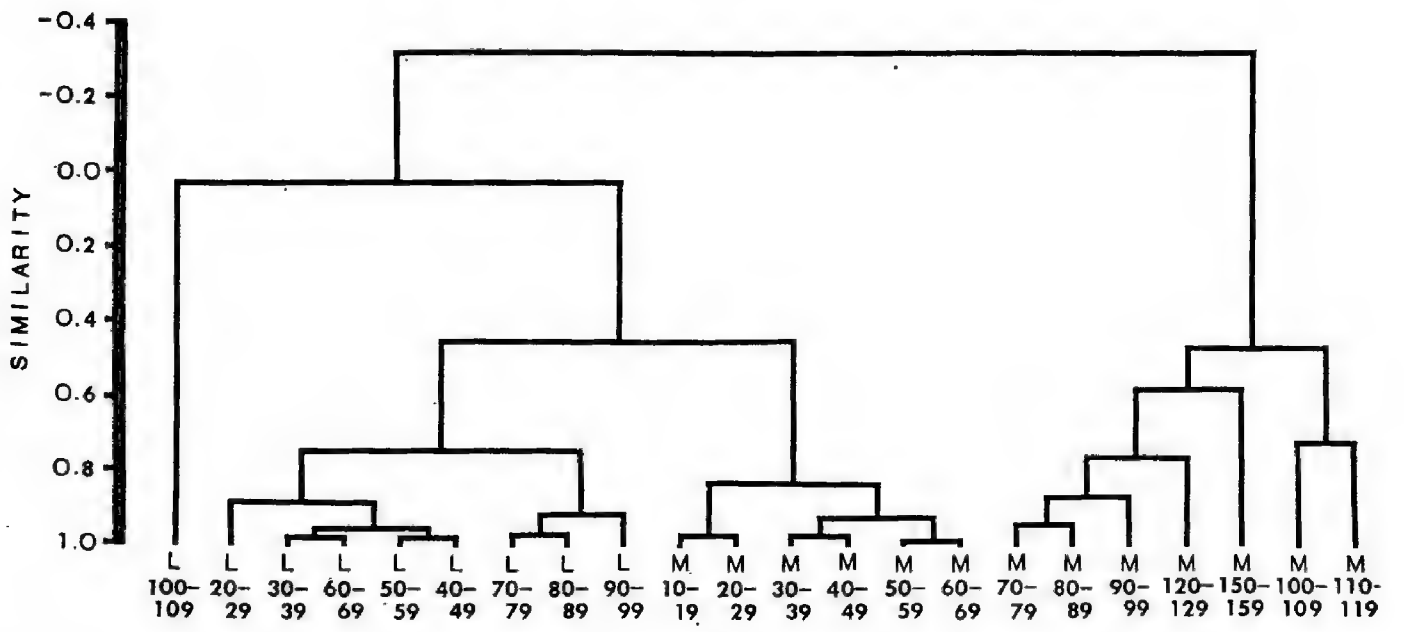

FIG. 2. Dendogram indicating intra- and interspecific feeding similarities of various size classes of spot (L) and croaker (M). Size ranges are in standard length (mm).

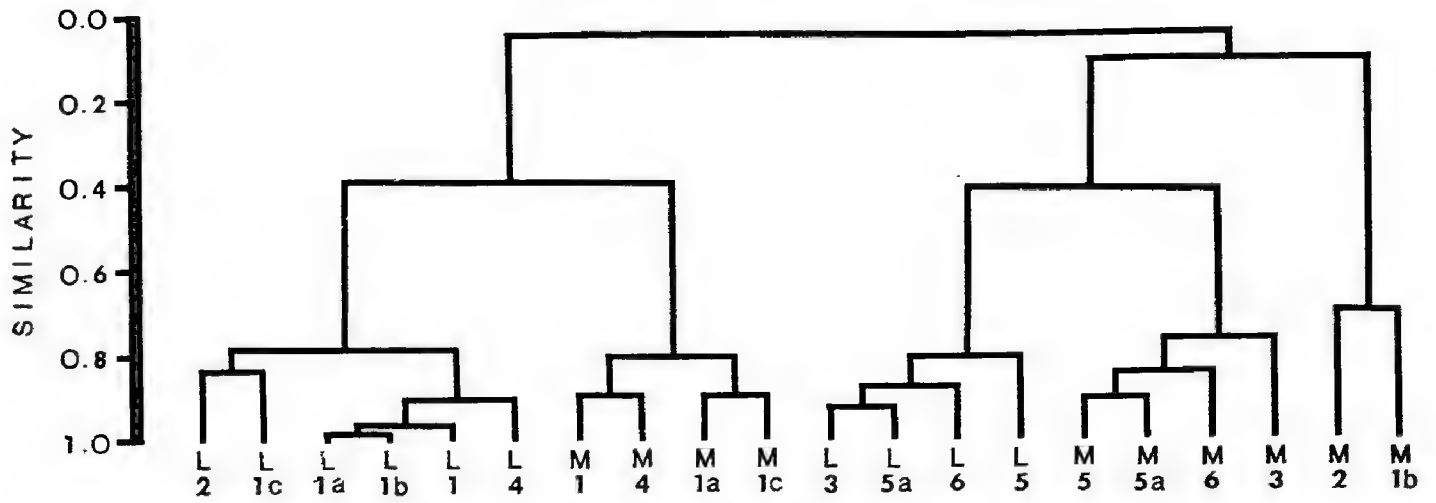

FIG. 3. Dendogram indicating intra- and interspecific feeding similarities of spot (L) and croaker (M) on a station-to-station basis.

were equally abundant in the East Bay area. In general, *Leiostomus* utilizes salt marsh and macrophyte habitats, as well as low salinity, high turbidity and color, mud bottom locations. *Micropogonias* is more habitat limited, using low to moderate salinity, mud bottom regions, especially those influenced by a highly turbid runoff.

Long-Term Fluctuations of *Micropogonias* and *Leiostomus*

Of the measured parameters within this system, most are highly correlated with either river flow, temperature or rainfall (Livingston *et al.* 1976). Some of these functions have been related to abundances of various commercial species. Sutcliffe (1972) found a significant relationship between river flow and commercial fisheries in Quebec. Rainfall, river runoff and temperature have a marked effect on brown shrimp production in Louisiana (Barrett and Gillespie 1973). Temperature has been frequently considered a determinant of commercial fishery stocks (Flowers and Saila 1972; Sutcliffe *et al.* 1977).

Catch/effort of *M. undulatus* and *L. xanthurus* in Apalachicola Bay and East Bay is compared to river flow, precipitation and air temperature in Figure 4. Taylor *et al.* (1957) studied the relationship between air and water temperature, which showed a good correlation over long periods of time. Daily air temperatures taken at Apalachicola, Florida were utilized rather than infrequent measurements of water temperature. Air temperature is also expressed in degree days, the differences between heating and cooling days summed daily for monthly periods, using 18.3° C as the mean. Most croaker and spot are bay residents only from November to June. The "year" is thus defined as beginning with the influx of juveniles (November 1) and ending the following June 30.

Annual variation of river flow apparently has minimal effect on fluctuations in abundances of either species. Peak numbers of *Micropogonias* occurred during years of lowest (1976) and highest (1973) river flow. Greatest numbers of spot were found during 2 years of low river runoff (1976, 1977). Few spot were collected, however, during the low river year of 1974. No relationship was found between rainfall and catch of either species. Highest rainfall usually did not

TABLE 3

Stomach contents (as % of total dry weight) of *Leiostomus xanthurus* by size class, summed over all stations and sampling dates.

Food Item	Size (mm) 20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	Avg. 20-109
Sand grains	0.3		0.2	0.2		0.3	2.1	1.6	0.3	0.2
Sediment masses					0.1	<.1				<.1
Detritus	19.7	21.4	14.5	12.5	11.8	27.2	33.4	33.0	14.4	16.3
Plant remains					<.1					<.1
Rhychocoels		<.1								<.1
Nematodes	8.8	12.6	9.6	8.3	7.1	8.2	7,2	4.3	3.0	9.7
Polychaetes	37.2	12.4	12.3	12.4	15.6	23.2	22.6	17.4		23.7
Gastropods				0.3	0.4					0.2
Bivalve siphons			0.7	0.1						<.1
Bivalves		5.8	12.5	11.5	2.4	8.8	8.7	21.3	69.9	10.8
Cladocerans	0.2	<.1		<.1						<.1
Ostracods					<.1					<.1
Calanoid copepods	5.2	5.6	1.1	3.6	5.1	3.8	7.0			4.7
Harpacticoid copepods	8.3	20.4	11.9	15.5	25.2	22.8	15.1	19.9	6.9	21.0
Cumaceans	0.2			0.3	0.6	0.4	1.4			4.0
Isopods		0.2	0.1	0.3	<.1					<.1
Amphipods	0.8	3.6	2.2	0.5	1.2	0.1	<.1		4.6	1.5
Mysids		3.2	1.4	5.4	1.3	3.0	2.1	2.2	0.8	2.6
Shrimp zoea					<.1					<.1
Crabs - zoeal			<.1		<.1					<.1
- megalopal			<.1							<.1
Insects - larval	19.3	12.9	32.8	28.8	28.3	2.0	0.6	0.2		8.4
- adult			0.1	<.1						<.1
Invertebrate eggs		<.1	<.1	<.1						<.1
Fish eggs			<.1	<.1	<.1					<.1

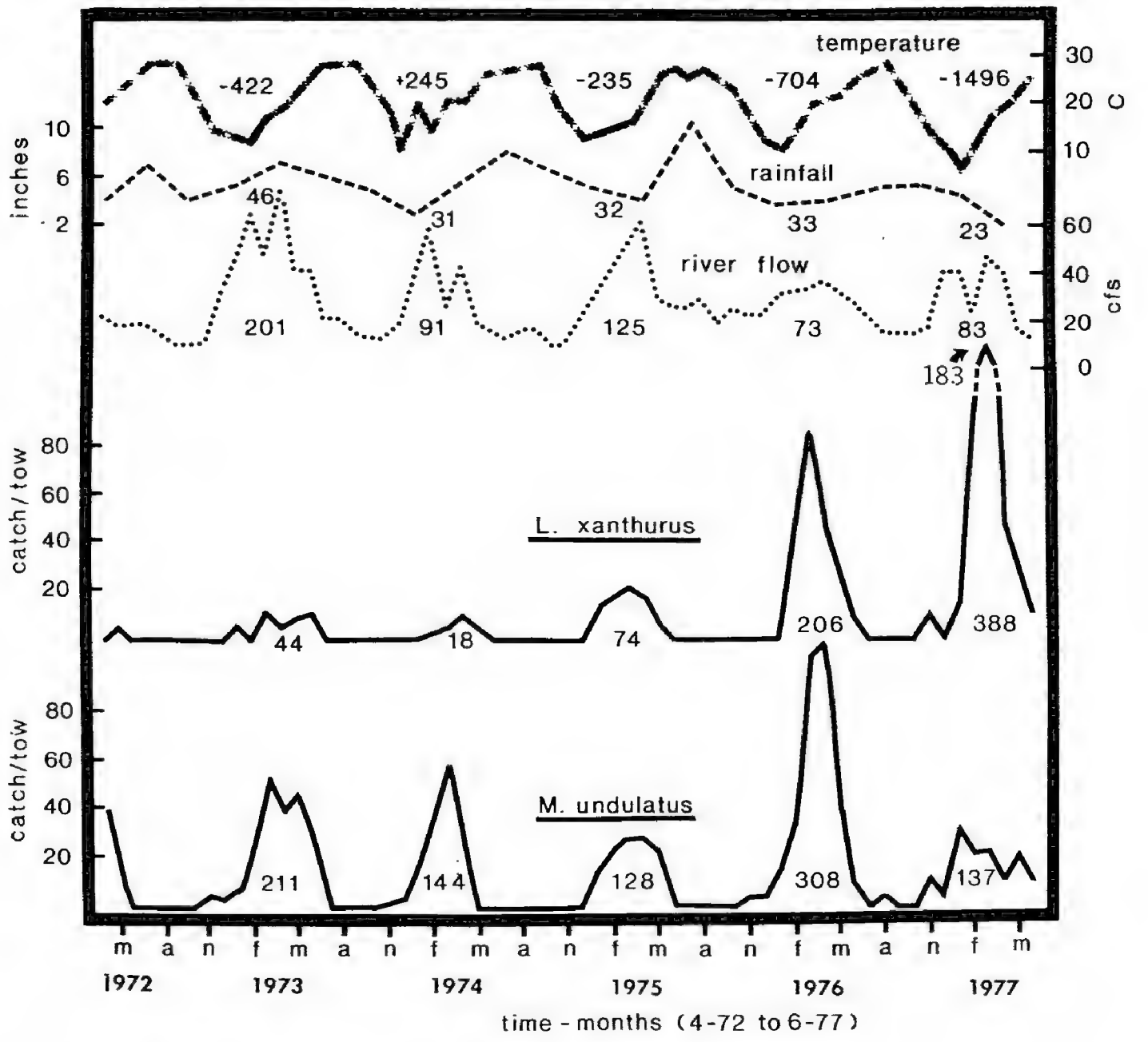

FIG. 4. Catch/effort of *M. undulatus* and *L. xanthurus* compared to mean monthly flow of the Apalachicola River (cfs), mean seasonal precipitation (inches), and mean monthly air temperatures (°C). Totals for each year include monthly summaries of: catch/effort of croaker and spot during November–June, river flow exceeding 20,000 cfs during November–June, rainfall during November–June, and temperature (degree days) during October–May.

coincide with peak numbers of fishes (November–June), and probably had little effect on temporal fluctuations. No consistent relationship was found between catch of croaker and temperature. An inverse relationship between temperature and abundance of spot was observed.

October, November, December and January are critical spawning and larval development months for *Micropogonias* and *Leiostomus*. Temperature expressed as degree days during this four month period, is compared with yearly catch/effort of spot for the five year study period (Figure 5). Linear regression showed catch of spot is inversely related to temperature ($r = 0.97$, $p < 0.01$). Lower average water temperatures during October–January are associated with an increase in catch. No lag time was added to the computations, as the majority of the fishes are of the 0 age class. No significant correlations were found between

catch of croaker and temperature, rainfall or river flow during any time period. No relationship was shown between catch of spot and river flow or rainfall.

The increased catch of both fishes during 1976 and subsequent decline of croaker during 1977 is not readily explainable. Apparently spot were well suited to the extremely low temperatures incurred during the fall and winter of 1976–77. The decreased catch of croaker during 1977 could reflect a greater susceptibility of this fish to low temperatures. Reproductive patterns of *L. xanthurus* and *M. undulatus* might have evolved such that occurrence of juveniles coincides with peak river flow. Juveniles (up to 15 mm) of these species are primarily planktivorous and may depend on the annual flooding of the Apalachicola River for resources. Yearly fluctuations in catch/effort of both species, however, had no relationship to patterns of river flow.

Interspecific competition could also induce fluctuations in population size. Both croaker and spot are benthic feeders and potentially extensive competition interactions were expected. Intraspecific similarities in diet, however, exceeded interspecific similarities on a size basis (Figure 2). Chao (1976) noted that compared to croaker, spot have smaller mouths, more numerous gill rakers, shorter outer gill rakers and longer inner gill rakers. This feeding apparatus permits retention of smaller food particles and prevents ingestion of relatively large food items. Thus, spot are able to exploit smaller food items such as harpacticoid copepods (avg. 21%) and nematodes (avg. 10%) but not shrimp, crabs or fish. Croakers, on the other hand, depend little upon harpacticoid copepods (2%) or nematodes (1%) but are able to consume large amounts of shrimp, crabs or juvenile fish when available. Splitting of available trophic resources enables the two species to coexist when their temporal and spatial distributions are quite similar.

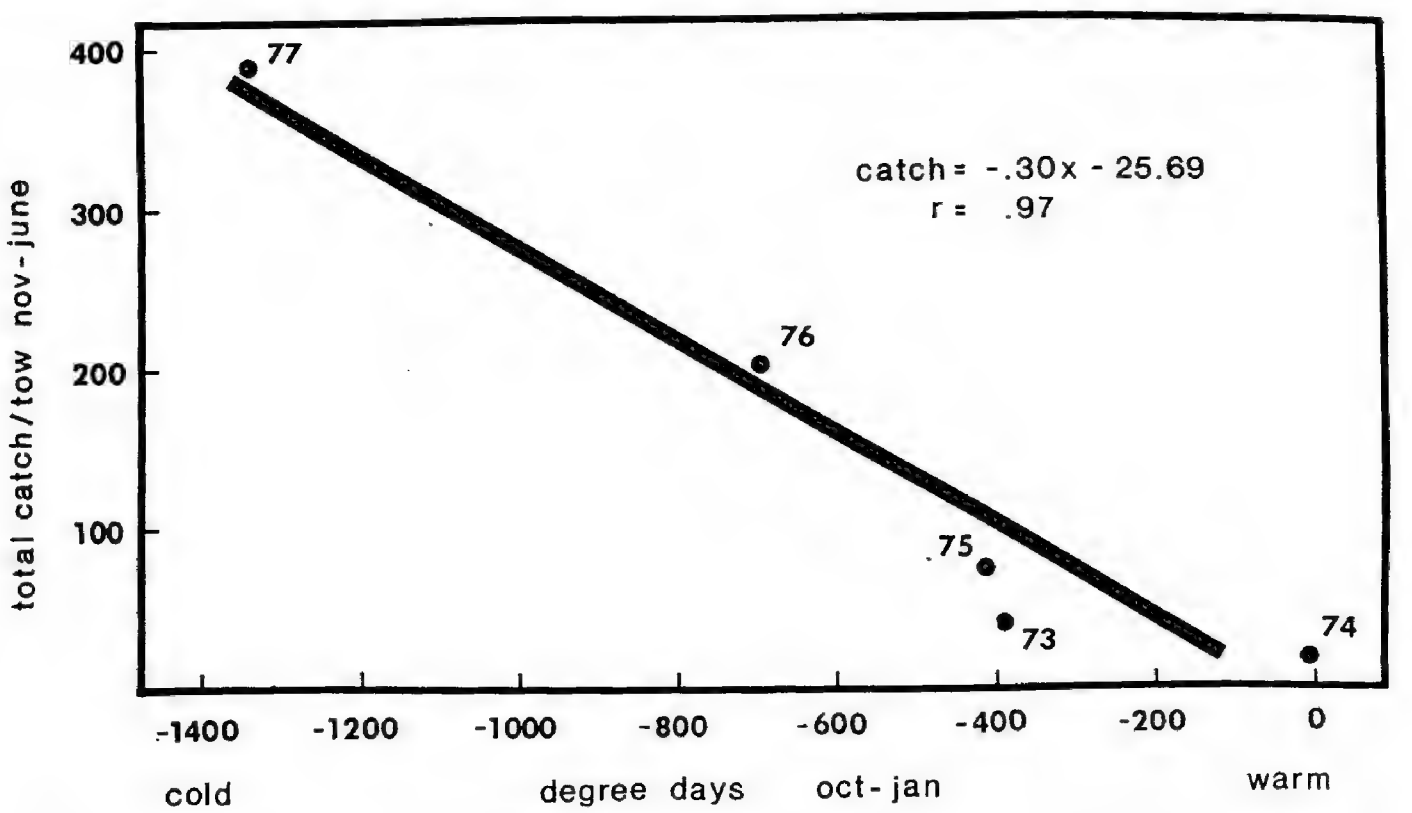

FIG. 5. Total catch/effort of *L. xanthurus* during November–June related to total degree days for October–January of each year (1973–1977) in the Apalachicola Bay System.

Of the known environmental parameters in the Apalachicola Bay System, only temperature was a significant determinant of long-term abundances of *L. xanthurus*. Temperature, river flow, and rainfall could not be related to annual fluctuations of numbers of *M. undulatus*. Competition for spatial and temporal resources and predation by other species is not well understood but could contribute to annual population variations. Apparently long-term abundances of spot and croaker are determined by a complex interaction of physical factors and biological functions.

ACKNOWLEDGMENTS

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OBSERVATIONS ON THE BIOLOGY OF SAND SEATROUT (*CYNOSCION ARENARIUS*) IN GALVESTON AND TRINITY BAYS, TEXAS

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ABSTRACT

Sand seatrout (*Cynoscion arenarius*) is of commercial and recreational importance to the Gulf states. Spawning behavior, feeding habits, length-weight relationships and standard length-total length relationships were determined for 498 sand seatrout collected between May 1966 and March 1968 from Galveston and Trinity Bays, Texas and from the Gulf of Mexico near Galveston Island.

Sand seatrout distribution, gonadal development and the time young-of-the-year appeared in estuaries indicated that this species spawns near Gulf-to-bay passes in the Gulf of Mexico between March and August with a spawning peak during spring. Fish and crustaceans dominated the diet of sand seatrout, crustaceans occurred more frequently in fish <160 mm SL and fish predominated in those >160 mm SL.

The length-weight regressions derived from 267 sand seatrout 125–375 mm SL differed between sexes. The standard length-total length relationship was $TL = 0.7 + 1.1$ SL.

INTRODUCTION

Sand seatrout (*Cynoscion arenarius*) inhabit estuaries and Gulf waters from southwest Florida to the Gulf of Campeche (Hildebrand 1955; Briggs 1965; Miller 1965; Moore, Brusher and Trent 1970; Franks, Christmas, Siler, Combs, Waller and Burns 1972). The distribution of sand seatrout appears to be restricted more by water temperature than by salinity (Trent, Pullen, Mock and Moore 1969). Along the Gulf coast sand seatrout have been collected at 6–37 C, but they are found in greatest abundance at temperatures of 20–24 C or higher (Copeland and Bechtel 1974, Gallaway and Strawn 1974). This species tolerates salinities of 0–45‰ (Simmons 1957, Roessler 1970). There is some indication that young sand seatrout are found at lower salinities than old fish (Gunter 1945).

The sand seatrout is economically and recreationally important to Texas. Heffernan, Green, McEachron, Weixelman, Hammerschmidt and Harrington (1976) estimated that it made up 12% (250,000 kg) of the total weight of all fishes caught by sport fishermen in Galveston, San Antonio, Aransas and upper Laguna Madre Bays between September 1974 and August 1975. In Galveston

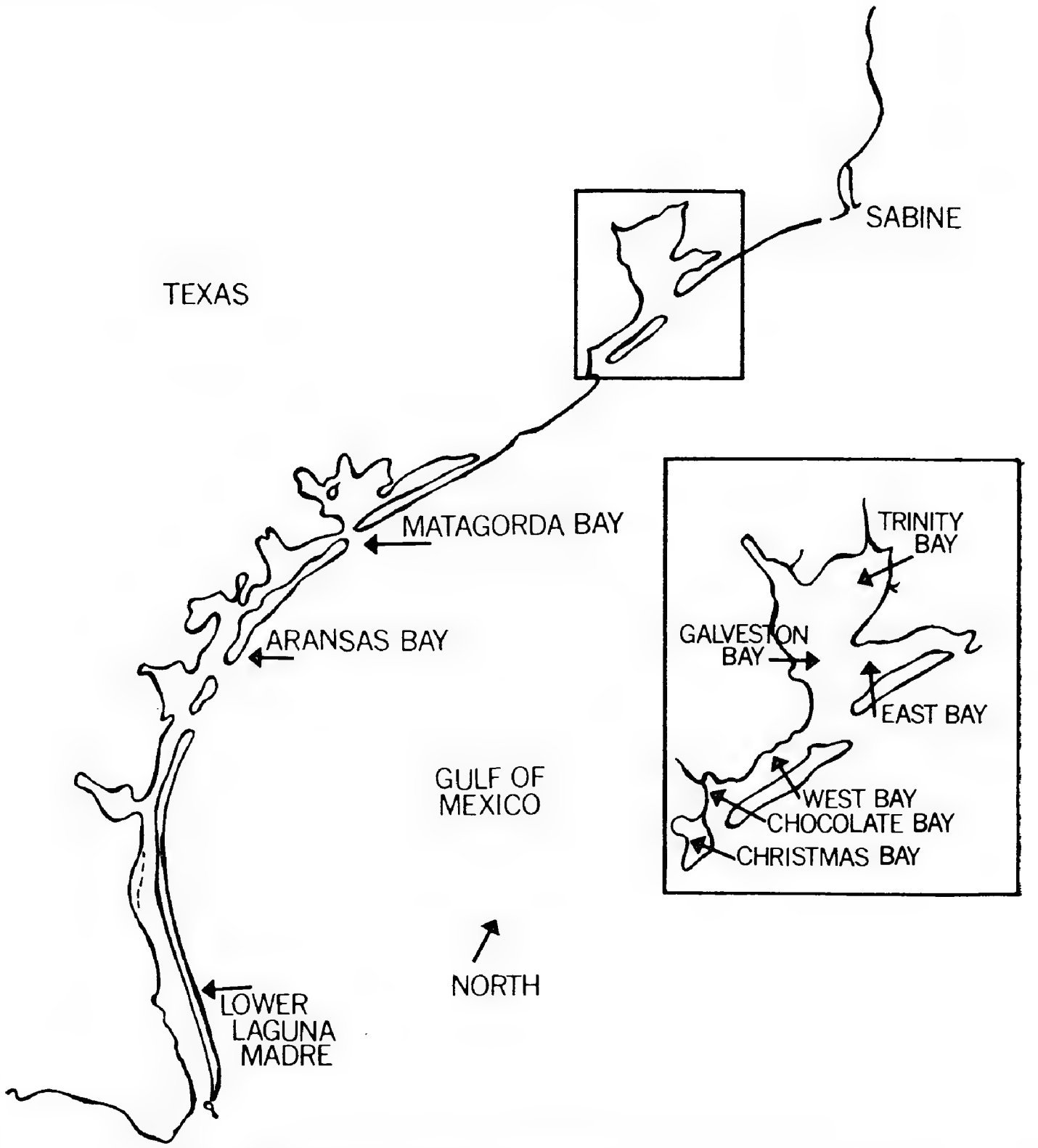

FIG. 1. Map of Texas Coast, Galveston Bay and Trinity Bay.

Bay the sand seatrout catch (212,000 kg) was exceeded only by the spotted seatrout (*C. nebulosus*) catch (1,017,000 kg).

The Texas commercial catch averaged 5017 kg/yr from 1968 to 1975 (O. B. Lynam, personal communication, Texas Parks and Wildlife Department, Seabrook, Texas), but these records are inaccurate because silver seatrout (*C. nothus*) are included and both are marketed as "white trout." The commercial landings and value of white trout at other Gulf states exceed those of Texas. From 1952 through 1974 landings ranged from 16,000 to 126,000 kg in Florida (west coast), from 5,000 to 722,000 kg in Alabama, from 12,000 to 841,000 kg in Mississippi and from 9,000 to 69,000 kg in Louisiana (Bureau of Commercial Fisheries 1952–1968, National Marine Fisheries Service 1969–1974).

Little has been published concerning the spawning habits, feeding, length-weight relationships of standard length (SL)-total length (TL) relationships of sand seatrout. Because of the commercial and recreational value of this species to the Gulf states, such information is needed in order to assist in formulating management plans for the Gulf sand seatrout stock. This paper presents spawning, feeding, length-weight and SL-TL data based on studies of sand seatrout collected by Texas Parks and Wildlife personnel from the Galveston Bay area (Fig. 1) during May 1966–March 1968.

MATERIALS AND METHODS

The 498 sand seatrout for this study were caught on rod and reel in Galveston Bay and in the vicinity of the Gulf jetties at Bolivar Roads near Galveston. Standard lengths (anterior end of lower jaw to caudal crease) and total lengths (anterior end of lower jaw to end of longest caudal ray) were measured (mm), and a standard length-total length regression was derived. Whole (ungutted) fish were weighed (g). Sex and maturity stages were recorded, maturity being determined by the method of Tabb (1961). Length-weight relationships were determined individually for both sexes and an analysis of covariance was done on the results. Stomach contents were removed and identified from 362 sand seatrout.

RESULTS

Spawning

Peak spawning occurred in spring. Ripe and spent females predominated in March but were scarce in summer, fall and winter (Table 1).

TABLE 1.

Sexual maturity stage numbers of sand seatrout 135–410 mm SL caught in Trinity Bay, Galveston Bay and the Gulf near Galveston, Texas (1966–1968).

	Maturity Stages											
	MALE						FEMALE					
Month	II	III	IV	V	VI	Total	II	III	IV	V	VI	Total
May	2	1				3	18	7				25
June	1	1				2		2	2			4
July		1			1	2	2					2
Aug.	23	1		1		25	21	10	1			32
Sept.	22					22	35	2	1		1	39
Oct.	16					16	20					20
Nov.	15					15	9					9
Dec.	7			1		8	1	1				2
Jan.	3	3	2			8	15	20	6	4-		45
Feb.	4	23	21	12	1	61	13	36	13	4		66
Mar.	5	14	4	2		25	10	15	7	33	2	67

II newly maturing
III fat storage or first ripening stage
IV fat absorption or second ripening stage
V ripe
VI spent

Feeding

Of the stomachs examined from 362 sand seatrout, 45–375 mm SL, 220 contained food. Fish were found in 40.9% of the stomachs, crustaceans in 18.1%, annelids in 0.8% and unidentified material in 2.4% (Table 2).

Since there appeared to be a shift in food preference from crustaceans to fish at about 160 mm (SL), fish were grouped into two size classes. Of the stomachs examined from 97 sand seatrout 45–159 mm SL, 67 contained food. Crustaceans were found in 38.1% of the stomachs, fish in 29.5% and unidentified material in 6.7%. Of the 27 stomachs removed from fish caught in the fall, 25 contained penaeid shrimp, perhaps reflecting the fall availability of white shrimp (*Penaeus setiferus*) (Table 3).

Of the stomachs examined from 265 sand seatrout 160–375 mm SL, 45.6% contained fish, 10.2% contained crustaceans, 1.1% contained annelids and 0.7% contained unidentified material. Bay anchovy (*Anchoa mitchilli*) were found in 82 of the stomachs; 75 of these fish were caught in the fall near gas-well flares in Galveston Bay, perhaps indicating an attraction of sand seatrout and anchovy schools to the light.

TABLE 2.

Percent frequency occurrence of food items in stomachs of 362 sand seatrout, caught in Trinity Bay, Galveston Bay and the Gulf near Galveston, Texas (1966–1968).

Food item	Sand seatrout 45–159 mm SL (%)	Sand seatrout 160–375 mm SL (%)	Total (%)
Annelida	0.0	1.1	0.8
TOTAL	0.0	1.1	0.8
Crustacea			
Unidentified remains	4.8	1.1	2.2
Amphipod	0.0	0.4	0.3
Isopod	0.0	0.4	0.3
Penaeidae	25.7	6.4	11.8
Portuidae	7.6	1.9	3.5
TOTAL	38.1	10.2	18.1
Fish			
Unidentified remains	22.9	12.9	15.7
Brevoortia patronus	0.9	0.4	0.5
Anchoa mitchelli	2.9	31.1	23.0
Micropogon undulatus	0.9	0.4	0.5
Mugil cephalus	0.9	0.4	0.5
Cynoscion nebulosus	0.0	0.4	0.3
Cynoscion arenarius	0.9	0.0	0.3
TOTAL	29.5	45.6	40.9
Unidentified material	6.7	0.7	2.4
TOTAL	6.7	0.7	2.4
EMPTY	25.7	42.4	37.7

TABLE 3.

Seasonal occurrence of food items in the stomachs of 362 sand seatrout caught in Trinity Bay, Galveston Bay and the Gulf near Galveston, Texas (1966–1968).

Sand seatrout 45–159 mm SL
Frequency of occurrence in stomachs

Food item	SEASON				Total
	Spring	Summer	Fall	Winter	
Crustacea:					
Unidentified remains	1	0	4		5
Penaeidae	0	2	25		27
Portunidae	0	0	8		8
Fish:					
Unidentified remains	15	6	3		24
Brevoortia patronus	1	0	0		1
Anchoa mitchelli	3	0	0		3
Mugil cephalus	0	1	0		1
Micropogon undulatus	0	1	0		1
Cynoscion arenarius	0	1	0		1
Unidentified material	3	4	0		7
Empty	6	20	4		30

Sand seatrout 160–375 mm SL
Frequency of occurrence in stomachs

Annelida	2	0	1	0	3
Crustacea:					
Unidentified remains	1	1	0	1	3
Amphipods	0	0	0	1	1
Isopoda	0	1	0	0	1
Penaeidae	0	4	12	1	17
Portunidae	1	0	3	1	5
Fish:					
Unidentified remains	18	4	11	1	34
Brevoortia patronus	1	0	0	0	1
Anchoa mitchelli	0	0	75	7	82
Mugil cephalus	0	0	1	0	1
Micropogon undulatus	0	1	0	0	1
Cynoscion nebulosus	0	1	0	0	1
Unidentified material	0	2	0	0	2
Empty	30	28	28	26	112

Length-weight Relationship

The length-weight relationship for 144 female sand seatrout 125–375 mm SL was log $W = -5.09429 + 3.11303$ log SL; this relationship for 123 males 135–350 mm SL was log $W = -5.12257 + 3.13132$ log SL (Fig. 2). An analysis of covariance indicated that these two equations differed ($F = 4.228$; d.f. = 1,264; $p < 0.05$).

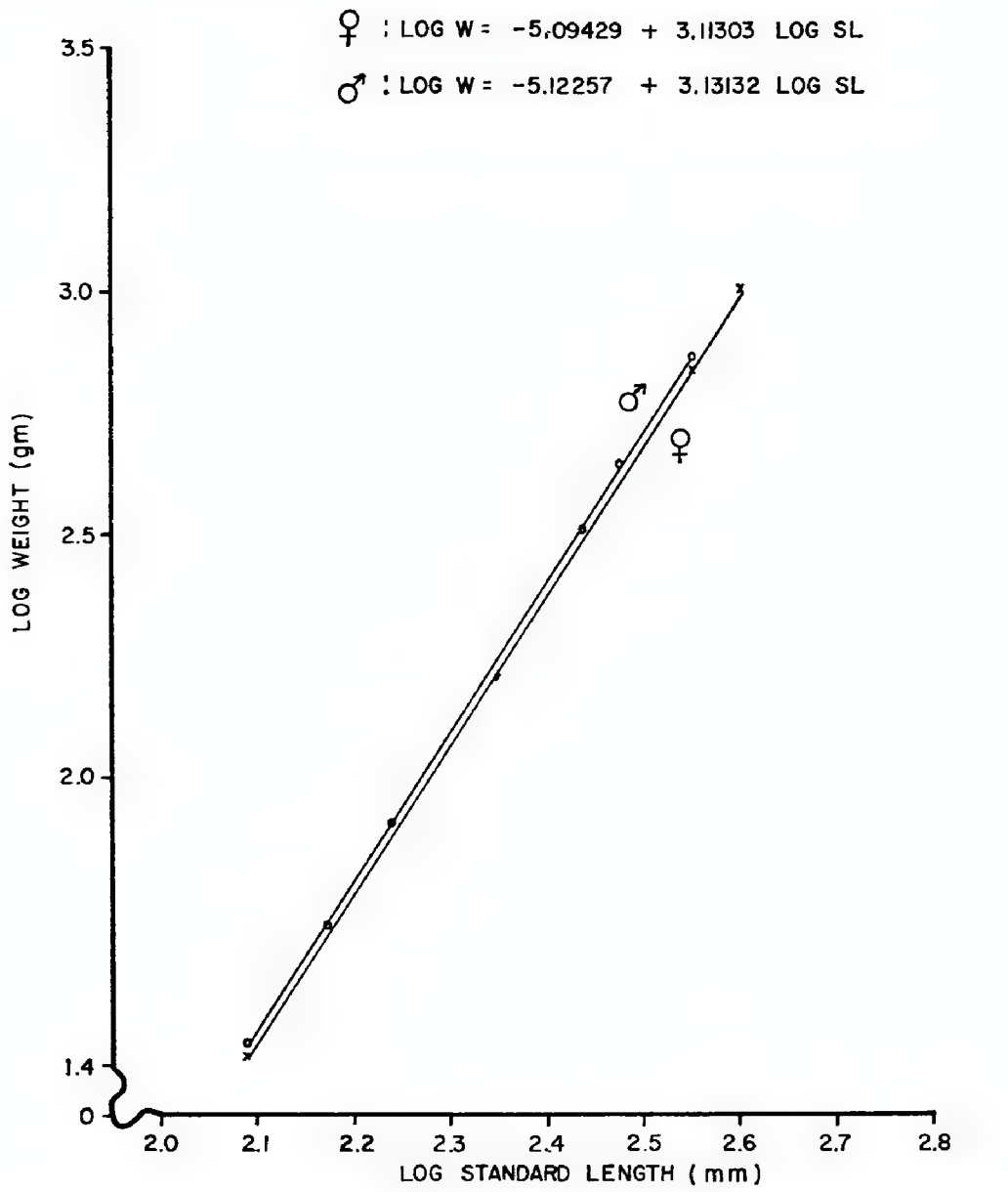

FIG. 2. Log weight-log standard length relationship for sand seatrout caught in Trinity Bay, Galveston Bay and the Gulf of Mexico near Galveston, Texas (1966–1968).

Standard Length-Total Length Relationship

The standard length-total length relationship based on measurements of 45 sand seatrout 63–310 mm SL is shown in Fig. 3. The linear regression equation for this line was $TL = 0.7 + 1.1\ SL$ ($r = 0.99$).

DISCUSSION

Spawning

There is some controversy over where sand seatrout spawn. Simmons (1951) and Simmons and Hoese (1959) described migration of mature fish from Aransas Bay into the Gulf via Cedar Bayou during May–August. Throughout summer they noted postlarvae and spent adults entering Aransas Bay on incoming tides. Franks *et al.* (1972) caught 45 ripe and "running" fish 35–37 cm TL at a 91-m deep station off Mississippi during March. Conversely, Copeland and Bechtel (1974) stated that "sand seatrout apparently spawn in the seaward portions of the estuary and is thus one of the few estuarine spawners." During

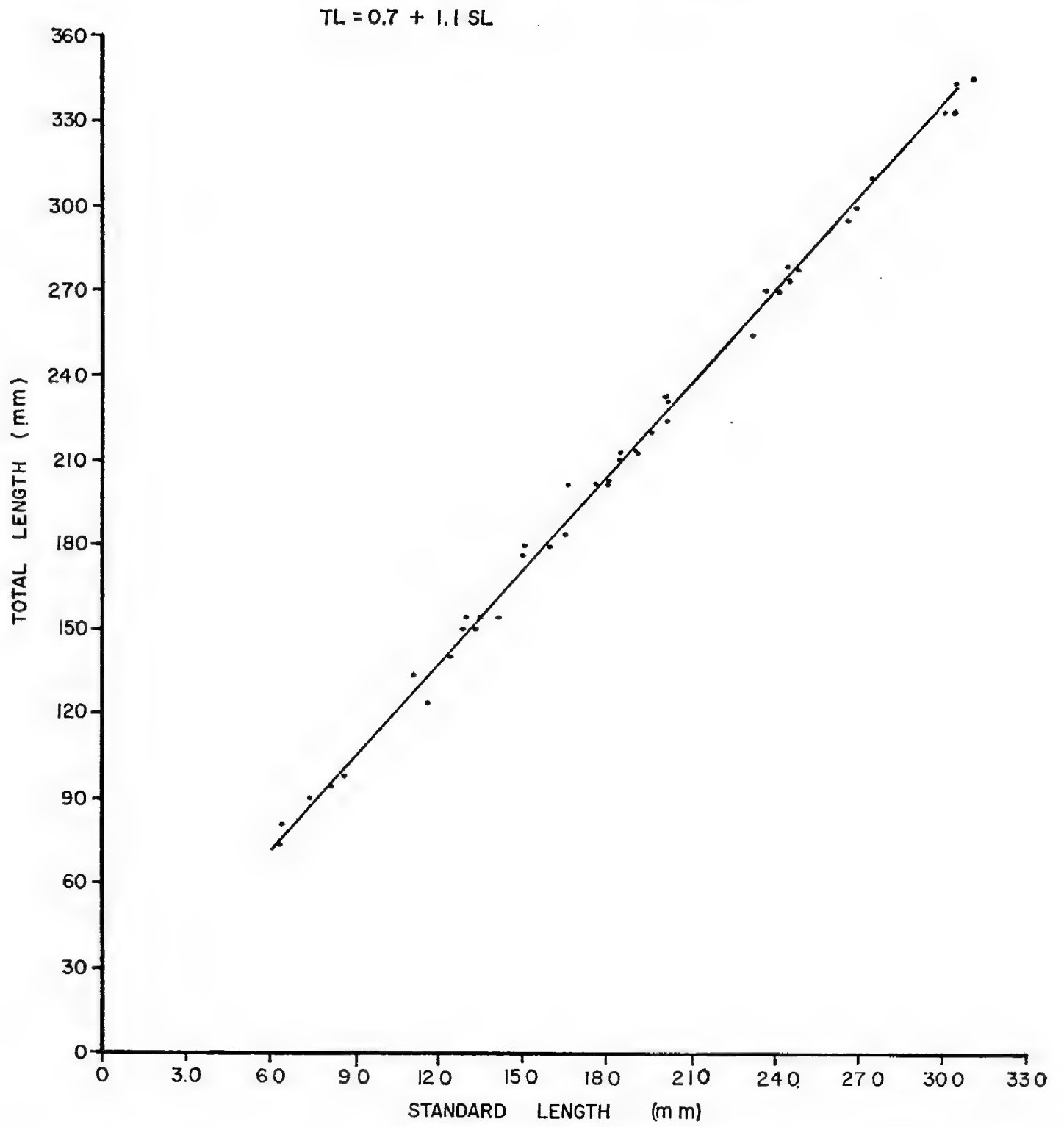

FIG. 3. Total length-standard length relationship for sand seatrout caught in Trinity Bay, Galveston Bay and the Gulf of Mexico near Galveston, Texas (1966–1968).

the present study ripe and spent fish were caught mainly during spring in the shallow Gulf near Galveston; the smallest ripe female was 18.5 cm SL and the smallest ripe male was 20.0 cm SL. Based on studies of the appearance of young-of-the-year fish in bays (Simmons 1951; Simmons and Hoese 1959; Benefield 1970; Franks *et al.* 1972; Christmas and Waller 1973; Moffett 1975; McEachron, Shaw and Moffett 1977), spawning has been estimated to occur generally between March and August.

Soft-bottom lakes and blind bayous in the Trinity River Delta of Galveston Bay are important sand seatrout nursery areas (Conner and Truesdale 1972). Sand seatrout also utilize salt marshes as nursery grounds for a short period

and then apparently move into open bay waters, Moffett (1975) having found fish as small as 18 mm SL in the open water of Chocolate Bay.

Feeding

Although it appears that sand seatrout exhibit a change in food preference as they grow (Table 3), the possibility that they are merely opportunistic, feeding on whatever is seasonally available, cannot be overlooked. Darnell (1958) noted a diet change in small sand seatrout in Lake Pontchartrain, Louisiana from copepods to schizopods to fish (bay anchovy). Reid (1955, 1956) and Diener, Inglis and Adams (1974) also found that crustaceans and fish were the primary food items of sand seatrout in Texas bays.

Length-weight Relationship

Matlock and Strawn (1976) reported a length-weight relationship of log W = −4.57970 + 2.92057 log SL (r = 0.991) based on measurements of 289 sand seatrout 14–119 mm SL from upper Galveston Bay. Vetter (1977) reported this relationship to be log W = −5.16 + 3.1494 log SL (r = 0.91) based on measurements of 52 fish 140–330 mm SL from Aransas Bay. Dawson (1965) reported a length-weight relationship of log W = −4.51150 + 2.89217 log SL based on measurements of 507 sand seatrout 40-205 mm SL from the Mississippi and Louisiana coasts.

The length-weight relationship presented in this study, closely resembles that presented by Vetter (1977); both of these investigations involved fish of similar sizes. The fish measured by Dawson (1965) and Matlock and Strawn (1976) were smaller and this might explain the difference between the regressions. However, Dawson's Mississippi-Louisiana sand seatrout may represent a distinct subpopulation; such subpopulations have been noted for spotted seatrout (Moffett 1961, Iversen and Tabb 1962, Weinstein and Yerger 1976). Therefore, studies are needed to determine if sand seatrout are separated into subpopulations and to determine the extent of intermingling. If the species is not continuous throughout its range, management measures affecting one group may have little application in other areas.

Standard Length-Total Length Relationship

No other data were found in the literature with which to compare the present standard length-total length regression. Since fish lengths are usually reported in the literature as *either* standard length *or* total length, such regressions are needed in order to make data from different sources comparable.

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DIEL ACTIVITY IN THE SPINY LOBSTER *PANULIRUS ARGUS* (LATREILLE)

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ABSTRACT

Ten Florida spiny lobsters, *Panulirus argus* (Latreille), were tested individually for 3-day periods in an electronic shuttlebox (Ichthyotron) under a natural LD15:9 photoperiod, to determine their diel pattern of locomotor activity. The diel activity pattern was bimodal (crespuscular), with a pronounced peak at dawn and a smaller peak at dusk. These peaks may be associated with changing light intensity, and correlate with field observations of this species' behavior.

Key Words: Diel Activity, Circadian Rhythms, *Panulirus argus*, Palinuridae, Spiny Lobster, Rock Lobster, Behavior.

INTRODUCTION

Locomotor activity patterns of decapod crustaceans have been shown to be influenced by numerous factors, including light intensity, photoperiod, temperature, season, social interactions, and shelter availability. For example, temperature affects activity of *Homarus americanus* (Reynolds and Casterlin 1979a), initiates mass seasonal migrations in *Panulirus argus* (Kanciruk and Herrnkind 1973, 1978), and affects diel activity patterns of *P. longipes cygnus* (Morgan 1978). Light intensity affects activity of *P. argus* (Sutcliffe 1956). Zeitlin-Hale and Sastry (1978) found that social interactions in groups of *H. americanus* tended to desynchronize activity patterns in the absence of shelter; individually tested lobsters provided with shelter displayed the clearest locomotor rhythms. Kanciruk and Herrnkind (1973) suggested that photoperiod might be among the environmental variables inducing seasonal differences in activity patterns. Naylor and Atkinson (1976) presented field data indicating a crepuscular pattern of burrow emergence in *Nephrops norvegicus*, while Hammond and Naylor (1977) conducted laboratory studies employing photocell-monitored light beams to show that in-burrow activity was nocturnal although emergence from the burrow was crepuscular, and that the rhythm was endogenously controlled. Hindley and Penn (1975) compared results of laboratory studies employing infrared or white-light beams to monitor activity of *P. longipes*, in which general agreement indicated that white light, although detected by the lobsters, did not

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interfere with their nocturnal activity (although Sutcliffe (1956) noted that bright moonlight inhibited activity of *P. argus*). Morgan (1978) found a crepuscular activity pattern with a pronounced dawn peak in *P. longipes*, and noted that the dawn activity peak had been observed in other *Panulirus* species such as *P. japonicus* (Kubo and Ishiwata 1964). Reynolds and Casterlin (1979b) found a crepuscular activity pattern in *Penaeus duorarum*, with a major peak at sunset rather than at dawn.

"*Panulirus argus* is," noted Laverack (1974, p. 149), "a large spiny lobster of uncertain habits. Many large decapods are well known commercially and culinarily but not physiologically, behaviorally, or ecologically; and *P. argus* falls into this group." The species is noteworthy for its autumnal single-file mass migrations (Kanciruk and Herrnkind 1978), during which the animals remain active throughout the day (Kanciruk and Herrnkind 1973). The migrations are thought to be triggered by a sudden drop in water temperature (Kanciruk and Herrnkind 1978). When not migrating, *P. argus* move up to 400 m between den and feeding areas at dawn and dusk (Clifton, Vanderwalker and Waller, 1970; Herrnkind, Vanderwalker and Barr 1975; Walton and Herrnkind 1977). Reynolds and Casterlin (1979c) found that the preferred temperature of *P. argus* is 30°C.

METHODS

We obtained ten juvenile *P. argus* (35–60 mm in carapace length) from Carolina Biological Supply Co., which did not specify conditions of their capture. Animals were shipped air freight and arrived in good condition. Testing was begun immediately. Each animal was tested at 30°C individually for 72 hours in an electronic shuttlebox described in detail elsewhere (Reynolds 1977). Activity was monitored by photocell-monitored narrowly-focussed white-light beams, and quantified as light beam interruptions per hour. Natural lighting was provided through windows, but direct sunlight did not fall upon the animals in the shuttleboxes. Black plastic overhead shelters were provided in each chamber. No food was given during tests. The June photoperiod was LD 15:9. Data for all individuals was pooled, and results were expressed as hourly percentages of total 24-hour activity to show the diel pattern.

RESULTS

Over a total of 720 lobster-hours of testing (10 lobsters × 72 hours each), the total number of light-beam interruptions was 851; thus, the mean absolute hourly activity level was 1.18 units per hour (851/720). Expressed on the basis of pooled data for all individuals over a composite 24-hour period, hourly activity was 35.5 units per hour (851/24). To show the diel pattern, hourly activity is expressed as a percentage of the 24-hour total for all individuals (Fig. 1), so that the expected hourly activity with no pattern would be 4.2%/hour (100%/24 hours).

A markedly crepuscular pattern is evident (Fig. 1), with peaks at dawn and dusk (crepuscular mean = 14%/hour). The dawn peak (18.4%/hour) was twice the height of the dusk peak (9.6%/hour). The peaks coincided with times of sunrise and sunset, showing neither anticipation nor lag. Diurnal and nocturnal activity averaged 3.2%/hour and 3.4%/hour, respectively.

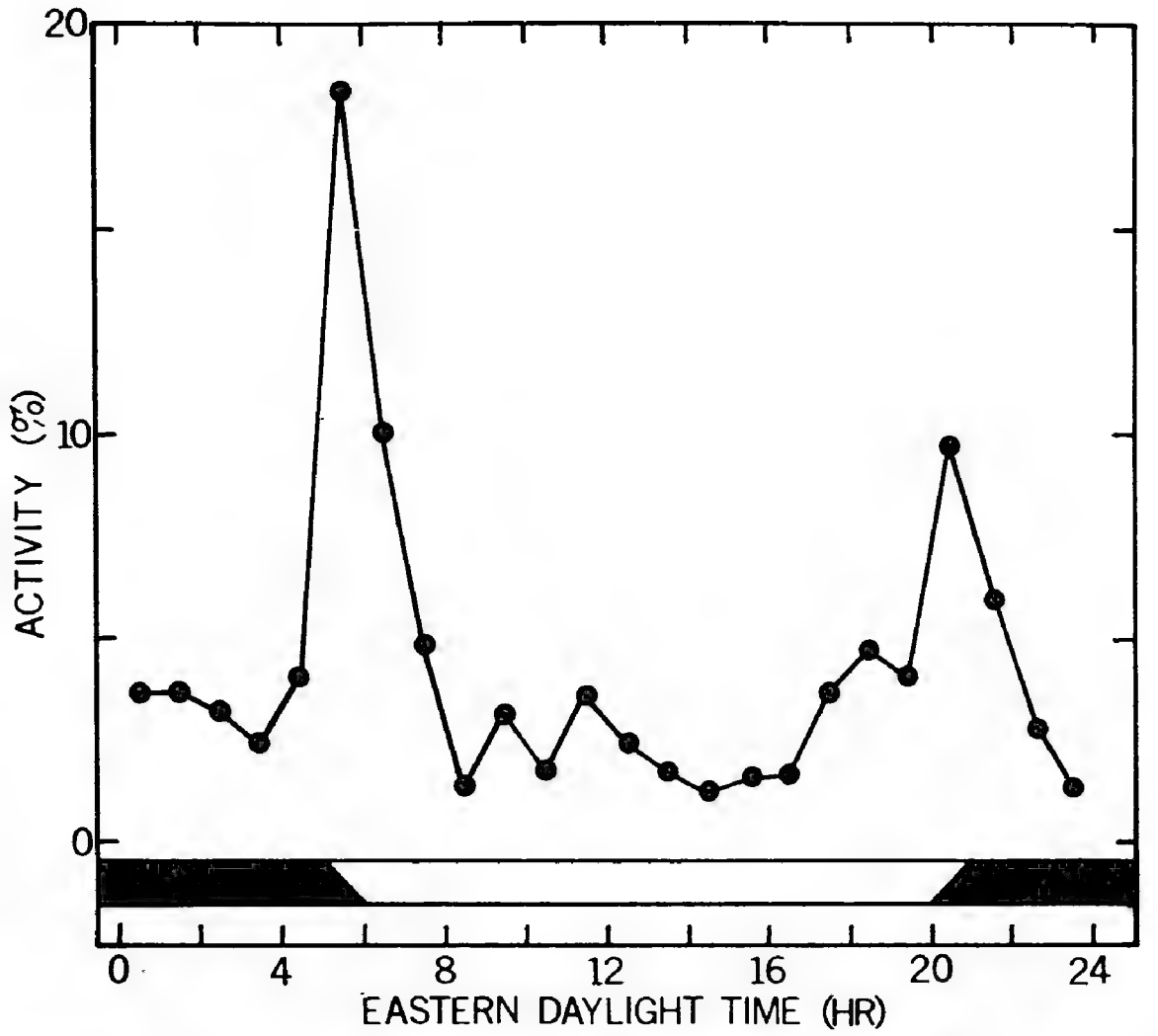

FIG. 1. Locomotor activity, quantified as photocell-monitored light-beam interruptions in an electronic (Ichthyotron) shuttlebox, expressed as hourly percentages of total 24-hr activity to shadow the diel patterns. Data was pooled for ten *P. argus* tested individually for 3-day periods. The photoperiod (natural June lighting through windows) is represented by the horizontal bar at the bottom; the shaded portion is night, the unshaded portion day, with tapered crepuscular transitions at dawn and dusk.

DISCUSSION

Our results (Fig. 1) are nearly identical to those reported by Morgan (1978) for *P. longipes*: a crepuscular pattern with a major peak at dawn, such as Kubo and Ishiwata (1964) found also for *P. japonicus*. This contrasts, however, with the longstanding opinion (Kanciruk and Herrnkind 1973) that *P. argus* is "a nocturnal animal." One might consider that the light beams employed in our apparatus (Reynolds 1977) may have depressed nocturnal activity (Sutcliffe 1956). However, Hindley and Penn (1975) have presented evidence that white light beams do not interfere with activity patterns of *P. longipes*, which Morgan (1978) also found to be crepuscular. Temperature might be a factor (Morgan 1978), as our tests were conducted at the preferred temperature (30°C) of *P. argus* (Reynolds and Casterlin 1979c), while Kanciruk and Herrnkind (1973) employed much lower temperatures (21–24°C). Another factor might be social interactions; Kanciruk and Herrnkind (1973, 1978) found nocturnal activity in groups of *P. argus*, while our tests were conducted with isolated individuals in view of Zeitlin-Hale and Sastry's (1978) finding that social interactions

inhibited activity and desynchronized activity patterns in groups of *H. americanus*, while individuals provided with shelter exhibited the clearest entrained rhythms. Field observations (Clifton, Vanderwalker and Waller 1970; Herrnkind, Vanderwalker and Barr 1975; Walton and Herrnkind 1977) of *P. argus* indicate that the major activity at night is feeding, while the most extensive movements (between den and feeding areas, up to 400 m distant) occur at dawn and dusk. Since we did not feed our animals during testing, it is obvious that we did not measure feeding activity; presumably, our measurements reflect the movements that would occur between den and feeding areas at dawn and dusk, which might be prompted by internal time cues or by changing light intensities at dawn and dusk. The increasing light intensity at dawn might be the signal that it is "time to go home," while decreasing light intensity at dusk might signal "dinnertime" or "it is safe to come out." Nocturnal feeding could be related to temporal availability of their food items, but as *P. argus* apparently is rather euryphagic (Zeiller 1974), this does not appear likely. Alternatively, nocturnal activity might be related to predator avoidance. Diving observations by the second author (W.W.R.) in the Gulf of California indicate that *Panulirus* species often venture out of their dens during daylight hours at greater depths, suggesting that light intensity may indeed be the salient proximate factor, and that predator avoidance might be the ultimate factor involved. However, the den areas are also frequented by moray eels which often eat crustceans, as we have observed in the field and laboratory. A further question remains: if nocturnality, or preference for low light intensities, is related to predator avoidance, how much greater predation mortality of *P. argus* during its autumnal migrations when it remains active during daylight hours in shallow water and even over open sand bottoms (cf. Kanciruk and Herrnkind, 1978, p. 602) affording no shelter from predators?

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SYSTEMATIC LIST OF THE SEAWEEDS OF SOUTH TEXAS*

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ABSTRACT

Recent collections add 37 species to the benthic marine algal floral of South Padre Island. Earlier collections were examined and annotated. Taxonomic revisions are incorporated into this checklist.

INTRODUCTION

The seaweeds of Port Isabel, Texas, and the neighboring south end of Padre Island have not been thoroughly documented. There is some information, however, in various papers dealing with Texas marine algae (Taylor 1936, 1941a, 1941b, 1954; Breuer 1962; Humm and Hildebrand 1962; Conover 1964; and Baca, Cox and Sorensen 1977). Wm. Randolph Taylor published the first list containing south Texas marine algae in 1936. It was made up of plants collected by Elzada Clover from Boca Chica (south of Padre Island), along with species from other parts of Texas collected by E. L. Cheatum or reported by M. A. Howe ("O. S.," 1931). The collections of Arthur Schott were published by Taylor (1941a, 1941b). The report listed some seaweeds collected at the mouth of the Rio Grande by Schott, along with others collected in south Texas by Clyde Reed or Robert Runyeon. In 1962, Joseph Breuer published a few species from south Texas in his largely ecological summary of the lower Laguna Madre. The same year, Harold Humm and Henry Hildebrand published the largest list to date, totaling 71 species from south Texas. John Conover (1964) presented the most complete ecological and seasonal periodicity studies, and his list contains 51 species collected from south Texas. Most recently, Baca, Cox, and Sorensen (1977) published minor ecological data and ranges of several south Texas seaweeds.

Since these early works, changes have occurred in south Texas flora due to floods (Sorensen 1963) and Hurricane Buelah in 1967. The long term changes in the flora caused by weather disturbances have been monitored carefully by one of us (LOS). Taxonomic revisions of marine algal groups by van den Hoek (1963), Aziz (1965), Kapraun (1969), Johansen (1970, 1971, 1976), Wynne and Taylor (1973), Fiore (1975), Yarish (1975) and others have appeared. Thus, the algal flora from this region needs re-evaluation.

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As evidenced by this list, the South Padre Island area is the locality for range extensions and range limits of certain seaweed species. This fact has been reinforced by our more complete knowledge of the flora of the upper Texas coast (Lowe and Cox 1978; Edwards 1970, 1976). Edwards' revised (1976) flora is the most complete modern treatise on Texas seaweeds. Microscopic epiphytes from this region cultured in the laboratory can be identified with the aid of Edwards' flora, and keys by Taylor (1960), Yarish (1975) and others.

Many intriguing questions concerning the ecology of the algae reported in this checklist have been noted as a result of this study. However, it is premature to make any broad ecological inferences at this time.

MATERIALS AND METHODS

This checklist is based on collections begun in the middle 1950's by Lazern O. Sorensen and continued through the present. Elenor R. Cox began collecting and cataloguing seaweeds from this area in 1971. More recent collections in conjunction with culture studies were begun by Bart J. Baca in 1975. Cultured material from our collections at South Padre Island was used to identify the microscopic epiphytes unless otherwise noted. Voucher specimens for this list have been placed in the Department of Biology Herbarium, Texas A&M University, College Station, Texas 77843.

Collection sites most commonly used for this list are as follows (see map, Figure 1).

I. North fishing jetty

This jetty is a granitic boulder structure exposed to turbulent wave action. Strong tidal flow exists in the adjacent Brazos Santiago channel which connects the Laguna Madre to the Gulf of Mexico. The water is often clear; however, turbidity is increased by muddy water from the Rio Grande River and bays of the Laguna Madre.

II. Bay near jetty

The nearest bay to the jetty has a mud bottom with a loose belt of granite rocks submerged near shore. Large tidal fluctuations occur, but the water is relatively calm and often clear.

III. U. S. Coast Guard Station

A variety of substrates exist here including seagrasses, rocks, and metal and concrete pilings. The water is turbid and often calm. During the collections, it was rich in organic matter from the nearby raw sewage effluent.

IV. Queen Isabella Causeway

The shallow flats adjacent to this structure are dominated by sea grasses, and large expanses are exposed during low tides. Much particulate matter exists in the water due to local drainage, decaying plant material and boat traffic.

V. *Acetabularia* flats

This area lies 11 km north of the Pan American Marine Biological Laboratory and 0.3 km off the west side of Park Road 100. It is a series of shallow seagrass and mud bottom flats and is partially exposed during low tides.

VI. Tarpon Hole

Named by residents for the fish once common here, this area is a seagrass lined shoal with a steep drop-off. Thick sedimentation occurs, with much decaying animal and plant matter from shrimp and fishing boats which dock near the U. S. Coast Guard Station and at Port Isabel. The water is usually turbid due to wind, boat traffic and drainage from local construction sites.

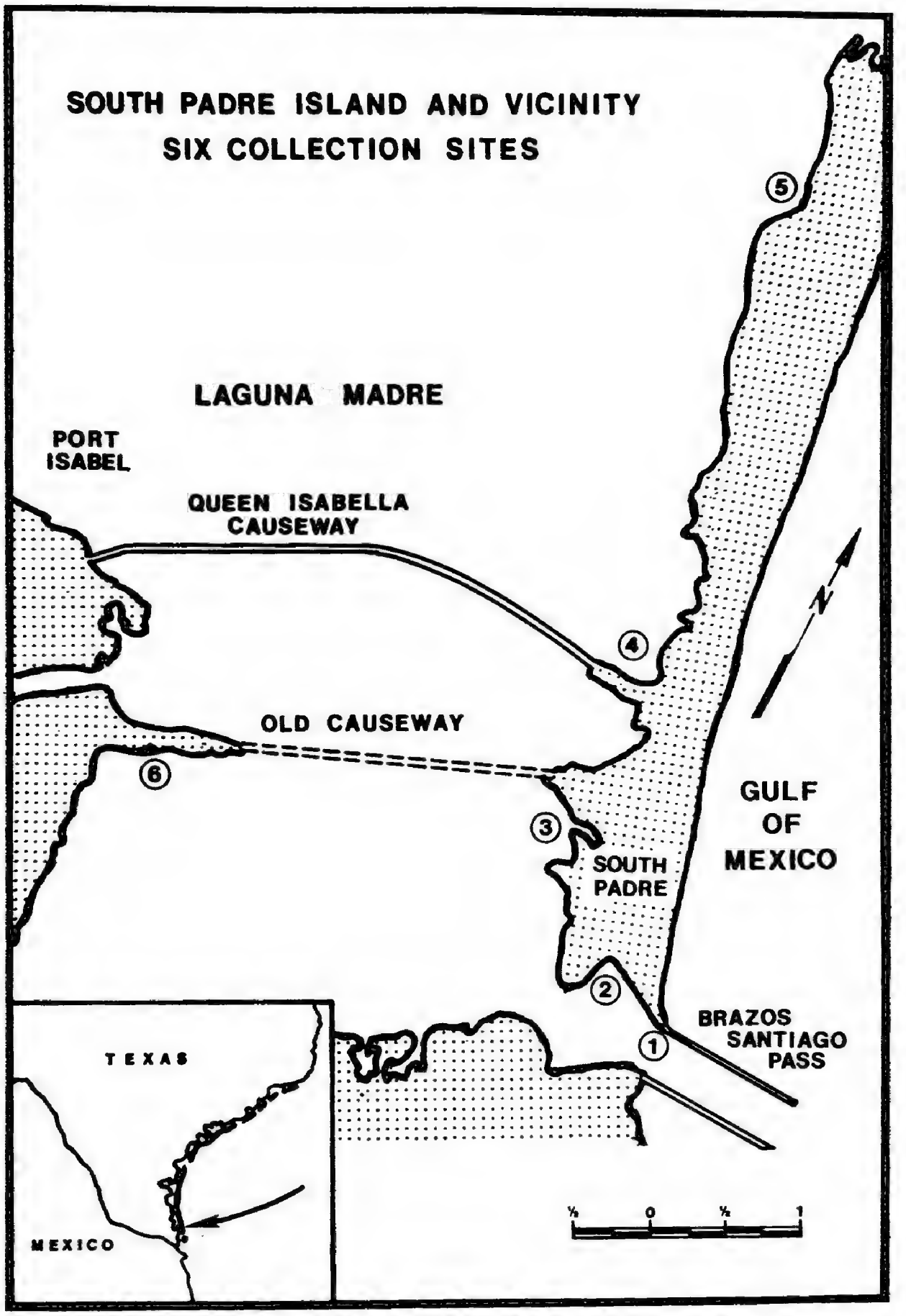

FIG. 1.

VII. Mansfield Cut

A few collections were made at the Mansfield Cut, which is the farthest north one can drive on the island. It is not included on Fig. 1, but lies approximately 40 km from the Brazos Santiago Pass. The jetties here are very similar to those at South Padre Island in composition and surrounding waters.

Arrangement of List

The format of this checklist is a modification of that used by Parke and Dixon (1964). The genera and species are arranged alphabetically under family, order and division. The classification is that of Bold and Wynne (1978). Roman numerals following each species indicate where we collected the algae at South Padre Island. If there is *no* Roman numeral after a species, we did not collect it during our investiagtions. Numbers in parentheses refer to descriptive notes listed at the end of the species list. Most of these notes refer to previous collectors, taxonomic revisions, or herbarium mounts when such were available for study. Invalid species, doubtful species, and synonyms are listed so that collectors unfamiliar with recent taxonomic changes can find them in the list. These are marked with a + before the name of the species. We have tried, after seeing the herbarium mounts of previous collectors or from the literature if no voucher specimen was available, to comment on all of the previous algal reports from this area. Since this is the first comprehensive account of the South Padre Island benthic algal flora, we believe such detail is essential to assist future workers in their understanding of the flora of this biogeographically important area of the Texas Gulf Coast.

SPECIES LIST

DIVISION CHLOROPHYCOPHYTA

Class CHLOROPHYCEAE

Order Ulotrichales

Family Ulotrichaceae

Ulothrix flacca (Dillwyn) Thuret III, VI, (1), (2), (3)

Order Chaetophorales

Family Chaetophoraceae (4)

Bolbocoleon piliferum Pringsheim III, VI, VII, (1), (2)

Entocladia flustrae (Reinke) Taylor (5)

E. ramulosa (Moewus) O'Kelly et Yarish I, VII, (1), (2), (6)

E. testarum Kylin I, IV, VI, VII, (1), (2)

E. viridis Reinke I, II, III, IV, VII, (1), (2)

Pseudulvella prostrata (Gardner) Setchell et Gardner III, IV, (1), (2)

Ulvella lens Crouan et Crouan III, (1), (2), (3)

Order Ulvales (7)

Family Ulvaceae

Enteromorpha clathrata (Roth) Greville III, IV, VI, (8)

E. flexuosa (Wolfen ex Roth) J. Agardh IV, V, VI, (8), (9), (10), (11)

E. lingulata J. Agardh II, III, (8), (11)

E. plumosa Kuetzing IV, (10)

E. prolifera (O. F. Mueller) J. Agardh IV, (10), (12)

E. salina Kuetzing IV, V, (1)

Ulva fasciata Delile I, II, III, IV, V, VI, VII, (8), (10), (11)

U. lactuca Linnaeus II, III, VI, (8), (10), (61)

Order Cladophorales (13)

Family Cladophoraceae

Chaetomorpha brachygona Harvey (10), (14)

C. clavata (C. Agardh) Kuetzing (11), (15)

C. linum (Mueller) Kuetzing I, II, III, VI, (1)

C. media (C. Agardh) Kuetzing (8), (15)

Cladophora albida (Hudson) Kuetzing VII, (1)
C. delicatula Montagne VI, (2), (8), (16)
+ *C. fascicularis* (Mertens) Kuetzing (8), (10), (11), (17)
+ *C. glaucescens* (Griffiths ex Harvey) Harvey (8), (18)
+ *C. gracilis* (Griffiths ex Harvey) Kuetzing (8), (18)
C. luteola Harvey (10), (15)
C. ruchingeri (C. Agardh) Kuetzing II, III, VII, (1), (19)
C. vagabunda (Linnaeus) v.d. Hoek II, III, VII, (17)
Order Caulerpales
Family Derbesiaceae
Derbesia sp. II, III, (1), (20)
Family Bryopsidaceae
Bryopsis hypnoides Lamouroux I, (10)
B. pennata Lamouroux (8), (15), (21)
B. plumosa (Hudson) C. Agardh I, III, VI, (1)
Family Caulerpaceae
+ *Caulerpa crassifolia* (f. *mexicana* Hauck?) (10), (22)
C. mexicana (Sonder) J. Agardh III, (8)
C. sertularioides (Gmelin) Howe (8), (15)
Family Phyllosiphonaceae
Ostreobium quecketii Bornet et Flahault (8), (23)
Family Udoteaceae
Penicillus capitatus Lamarck VI, (8), (10), (24)
Order Siphonocladales
Family Siphonocladaceae
Cladophoropsis membranacea (C. Agardh) Boergesen (10), (15)
Order Dasycladales
Family Dasycladaceae
Batophora oerstedi J. Agardh V, (10)
Actetabularia crenulata Lamouroux II, III, IV, V, VII (adrift), (8), (9), (10)

DIVISION PHAEOPHYCOPHYTA

Class PHAEOPHYCEAE
Order Ectocarpales
Family Ectocarpaceae
+ *Ectocarpus confervoides* (Roth) Le Jolis (10), (25)
+ *E. duchassaignianus* Grunow (10), (11), (26)
E. siliculosis (Dillwyn) Lyngbye II, III, IV, V, (8), (10)
+ *Giffordia duchassaigniana* (Grunow) Taylor (8), (10), (27), (28)
G. indica (Sonder) Papenfuss et Chihara VI, (2)
G. mitchelliae (Harvey) Hamel II, III, (2), (8)
G. rallsiae (Vickers) Taylor II, IV, V, (1), (2)
+ *Pilayella antillarum* (Grunow) De Toni (10), (29)
Streblonema oligosporum Stroemfelt III, (1), (2), (30)

Order Chordariales
Family Chordariaceae
Cladosiphon occidentalis Kylin III, IV, V, VI, (1), (2)
+ *Eudesme zosterae* (J. Agardh) Kylin (9), (10), (31)
Order Sphacelariales
Family Sphacelariaceae
Sphacelaria furcigera Kuetzing (8), (10), (15)
Order Dictyotales
Family Dictyotaceae
Dicteropteris delicatula Lamouroux (8), (15), (32)
Dictyota cervicornis Kuetzing (9), (15)
D. dichotoma (Hudson) Lamouroux I, II, III, VI, (8), (10)
D. indica Sonder in Kuetzing (8), (10), (15), (33)
Padina vickersiae Holt I, II, III, (8), (10)
Spatoglossum schroederi (Mertens) Kuetzing I, III, (34)
Order Dictyosiphonales
Family Striariaceae
Hummia onusta (Kuetzing) Fiore III, IV, V, VI, (1), (2), (35)
Family Myriotrichiaceae
+ *Myriotrichia subcorymbosa* (Holden) Blomquist (8), (36)
Order Scytosiphonales
Family Scytosiphonaceae
Petalonia fascia (Mueller) Kuntze II, IV, VI, (1)
Rosenvingea sanctae-crucis Boergesen III, VI, (1), (2)
Order Fucales
Family Sargassaceae
Sargassum filipendula C. Agardh I, II, (10), (11), (37)
S. fluitans Boergesen (8), (11), (38)
S. natans (Linnaeus) J. Meyen (8), (11), (38)

DIVISION RHODOPHYCOPHYTA

Class RHODOPHYCEAE
Subclass Bangiophycidae
Order Goniotrichales
Family Goniotrichaceae
+ *Asterocytis ornata* (C. Agardh) Hamel (8), (39)
A. ramosa (Thwaites) Gobi I, III, VI, (2)
Goniotrichum alsidii (Zanardini) Howe I, II, III, (2), (8)
Order Bangiales
Family Erythropeltidaceae
Erythrocladia subintergra Rosenvinge I, II, III, VI, VII, (1), (2)
Erythrotrichia carnea (Dillwyn) J. Agardh I, II, III, IV, V, VI, VII, (2), (10)
Family Bangiaceae
Bangia fuscopurpurea (Dillwyn) Lyngbye I, II, III, VII, (8)
Porphyra leucosticta Thuret I, II, VII, (1), (64)

Subclass Florideophycidae
Order Nemalionales
Family Acrochaetiaceae
Acrochaetium flexuosum Vickers II, III, VII, (1), (2)
A. hoytii Collins II, III, (1), (2)
A. seriatum Boergesen II, III, (2), (8)
A. virgatulum (Harvey) J. Agardh III, (1), (2)
Family Gelidiaceae
Gelidium corneum (Hudson) Lamouroux (8), (10), (15), (41)
G. crinale (Turner) Lamouroux I, II, III, VII, (8), (10), (11)
Pterocladia bartlettii Taylor I, VII, (1)
P. capillacea (Gmelin) Bornet et Thuret I, VII, (1)
Order Cryptonemiales
Family Cryptonemiaceae
Grateloupia filicina (Wulfen) C. Agardh I, VII, (8), (10)
Family Corallinaceae (42)
Fosliella farinosa (Lamouroux) Howe (8), (15)
+*F. lejolisii* (Rosanoff) Howe (10), (43)
Heteroderma lejolisii (Rosanoff) Foslie II, III, VI, VII, (2), (10)
Tenarea pustulatum (Lamouroux) Adey I, II, VII, (1), (2), (44)
Amphiroa fragilissima (Linnaeus) Lamouroux (8), (10), (15)
Corallina cubensis (Montagne) Kuetzing I, VII, (1), (2)
C. granifera Ellis et Solander (9), (15)
C. officinalis Linnaeus (10), (15)
+*C. subulata* Ellis et Solander (8), (45)
Halyptylon subulata (Ellis et Solander) Johansen I, VII
Jania capillacea Harvey IV, V, VI, (47)
+*J. decussato-dichotoma* (Yendo) Yendo (8), (15), (46), (47)
J. rubens (Linnaeus) Lamouroux (8), (15)
Order Gigartinales
Family Gigartinaceae
Gigartina elegans Greville (11), (15)
Family Solieriaceae
+*Agardhiella tenera* (J. Agardh) Schmitz (8), (10), (11), (48)
Neoagardhiella baileyi (Harvey ex Kuetzing) Wynne et Taylor II, III, IV, (1)
Solieria tenera (J. Agardh) Wynne et Taylor I, VII
Family Gracilariaceae
Gracilaria armata (C. Agardh) J. Agardh (8), (15), (49)
G. blodgettii Harvey IV, (8), (9), (10)
G. caudata J. Agardh (8), (15), (50)
G. crassissima Crouan et Crouan ex J. Agardh (10), (15)
G. debilis (Forsskal) Boergesen II, IV, V, VI, (1)
G. ferox J. Agardh (8), (15)
G. foliifera (Forsskal) Boergesen III, VI, VII, (10)

+*G. lacinulata* (Vahl) Howe (11), (51)
G. verrucosa (Hudson) Papenfuss II, IV, V, VI, (10)
Family Hypneaceae
Hypnea cervicornis J. Agardh (9), (11), (52), (53)
H. cornuta (Lamouroux) J. Agardh III, IV, V, (10)
H. musciformis (Wulfen) Lamouroux I, II, III, VI, VII, (8), (10), (11)
Order Rhodymeniales
Family Champiaceae
Lomentaria baileyana (Harvey) Farlow IV, V
+*L. uncinata* (8), (54), (55)
Champia parvula (C. Agardh) Harvey IV, V, VI, (1)
Family Rhodymeniaceae
Rhodymenia pseudopalmata (Lamouroux) Silva I, (8), (10)
Order Ceramiales
Family Ceramiaceae
Callithamnion byssoides Arnott in Hooker, I, II, III, VII, (2), (8)
C. corymbosum (J. E. Smith) C. Agardh (8), (15), (56)
Ceramium byssoideum Harvey I, II, VI, (2), (8)
C. fastigiatum (Roth) Harvey f. *flaccida* H. E. Petersen II, III, (2), (8)
C. strictum (Kuetzing) Harvey I, II, VII, (1), (2)
Centroceras clavulatum (C. Agardh) Montagne I, II, III, VI, VII, (2), (8), (10), (11)
+*Spyridia aculeata* (Schimper) Kuetzing (8), (10), (62)
S. clavata Kuetzing (8), (15)
S. filamentosa (Wulfen) Harvey II, IV, V, (8)
S. hypnoides (Bory) Papenfuss I, II, III, VI, (62)
Family Dasyaceae
Dasya rigidula (Kuetzing) Ardissone I, (2), (8)
Family Rhodomelaceae
Acanthophora spicifera (Vahl) Boergesen VI, (8), (10)
Bryocladia cuspidata (J. Agardh) De Toni I, II, VII, (8), (10) (11)
B. thyrsigera (J. Agardh) Schmitz II, VII, (1)
Chondria atropurpurea Harvey (10), (15)
C. cnicophylla (Melvill) De Toni III, IV, V, VI, (1)
C. curvilineata Collins et Hervey (8), (15)
C. dasyphylla (Woodward) C. Agardh IV, V, (1)
C. littoralis Harvey III, (1)
C. tenuissima (Goodenough et Woodward) C. Agardh (10), (15)
Digenia simplex (Wulfen) C. Agardh II, III, IV, V, (8), (10)
Herposiphonia tenella (C. Agardh) Ambronn I, II, III, VI, VII, (2), (8)
Laurencia intricata Lamouroux (8), (15)
L. poitei (Lamouroux) Howe II, III, IV, V, VI, (8), (11)
Polysiphonia denudata (Dillwyn) Kuetzing II, III, IV, V, VI, VII, (2), (8)

P. echinata Harvey I, II, III, VII, (1), (2)
P. ferulacea Suhr (8), (10), (57)
P. gorgoniae Harvey IV, V, (2)
P. hapalacantha Harvey (8), (58)
P. havanensis Montagne IV, V, (2), (8), (10), (59)
P. howei Hollenberg (8), (10), (60)
P. macrocarpa Harvey (10), (15), (63)
P. subtilissima Montagne IV, V, (2), (8)
P. tepida Hollenberg I, VII, (2)
Wrightiella tumanowiczii (Gatty) Schmitz (11), (15)

NOTES

1. First report of this alga from the study area.
2. Commonly found as an epiphyte on larger algae or seagrasses, or epizoic on shells at the study area.
3. The identification of this species is tentative until culture studies are performed.
4. Yarish (1975) has done a comparative study of this group, and our work relies on his guidelines for identification. However, recent work (O'Kelly and Yarish 1977) shows that taxonomic criteria such as setae and germ tubes are invalid for some species. Further study of isolates from the study area is needed.
5. Isolated from a Port Isabel jetty (Yarish 1975), but not found by present authors.
6. Conserved over *Ectochaete ramulosa* (O'Kelly and Yarish 1977).
7. This order has been well studied by Kapraun (1969) on the Texas coast, and this part of the list relies on his determinations.
8. Reported earlier from this area by Humm and Hildebrand (1962).
9. Reported earlier from this area by Breuer (1962).
10. Reported earlier from this area by Conover (1964).
11. Reported earlier from this area in one or more of the works of Taylor (1936, 1941a, 1941b and 1954).
12. A few plants were collected which conformed to this species, but their identification is tentative.
13. Identification of plants within this difficult group is facilitated by v. d. Hoek (1963) and v. d. Hoek's contribution in Edwards (1970, 1976); however, additional studies are needed for some south Texas and Mexican isolates.
14. A herbarium mount collected in south Texas and labeled *C. brachygona* (Hildebrand and Humm, Sept. 27, 1953) was examined, and is probably *C. linum*, but cannot be positively identified.
15. No plant was collected by the authors which conformed to this species. Its presence is, therefore, doubtful at this time.
16. Listed as frequent by Edwards (1970, 1976) for north of the study area, but was rare at the study area.
17. A herbarium mount collected in south Texas and labeled *C. fascicularis* (Hildebrand and Humm, Oct. 11, 1952) was examined and is *C. vagabunda.*

European plants labeled *C. fascicularis* have also been identified as *C. vagabunda* by v. d. Hoek (1963).

18. Considered synonymous with *C. sericea* (Hudson) Kuetzing by v. d. Hoek (1963). *C. sericea* was not found at the study area by the present authors.
19. Considered synonymous with *C. nitida* by Taylor (1960); however, retained by v. d. Hoek (1963). Easily confused with *C. sericea.*
20. Since reproductive structures were not observed, this species could not be identified. Further study is needed with local isolates of both *Derbesia* and *Bryopsis.*
21. Many small plants collected from bay or jetty habitats resemble *B. pennata,* but are variations of *B. plumosa.*
22. Considered by Taylor as synonymous with *C. mexicana* (Taylor 1960).
23. This species could not be isolated from shell fragments collected at the study area.
24. Despite attempts to reintroduce this species to the study area by Sorensen (1963), only a few plants can be found, and it remains a victim of low salinities and low temperatures which occurred in 1958 and 1962, respectively.
25. According to Edwards (1970, 1976) this species is synonymous with *E. siliculosus* for Texas isolates.
26. Removed to *Giffordia duchassaigniana* by Taylor (1960).
27. Removed to *G. indica* by Taylor (1973).
28. A herbarium mount collected in south Texas and labeled *G. duchassaigniana* (Hildebrand and Humm, Oct. 11, 1952) was examined, and best conforms to *G. rallsiae.*
29. An organism was isolated into culture which has intercalary sporangia, but it is difficult to identify because of its poor growth.
30. This species and *Streblonema* sp. as listed by Edwards (1970, 1976) were found in the study area along with another brown filament best conforming to J. Agardh's *Herponema* as amended by Hamel (in Taylor 1960). In addition, filamentous stages exist for various brown algae of the family Scytosiphonaceae (Wynne 1969; Edwards 1969; Loiseaux 1970; and Wynne and Loiseaux 1976), and since these are probably found in the field can add to the confusion.
31. Removed to *Cladosiphon zosterae* by Earle (1969), who also doubted the existence of both *C. occidentalis* and *C. zosterae* in the Gulf of Mexico. Rare plants were collected by the present authors which intergrade between the two species.
32. A herbarium mount collected in south Texas and labeled *D. delicatula* (Hildebrand and Humm, Oct. 11, 1952) was examined and verified, but this species is no longer present there.
33. Extremely long and thin examples of *D. dichotoma* found in this study area are easily confused with this species.
34. First reported from Texas by Baca *et al.* (1977) and from adjacent Mexico by Humm and Hildebrand (1962).

35. Shown to be the gametophyte stage of *Stictyosiphon subsimplex* Holden (Fiore 1975).
36. Plants conforming to this and related species are probably stages in the life histories of various filamentous brown algae (Fiore 1975).
37. A polymorphic species with the bay form and the jetty form exhibiting extreme interspecific differences.
38. Commonly found adrift at most stations.
39. Synonymous with *A. ramosa.*
40. Identifications within this group were facilitated by the monograph of Aziz (1965) and its application by Edwards (1970, 1976). The species listed are those placed into culture by the senior author (BJB).
41. Probably confused with *Pterocladia bartlettii* by earlier workers.
42. The generic concepts of Johansen (1976) were used in initial identifications within this family.
43. Listed for the Texas coast as synonymous with *Heteroderma lejolisii* by Edwards (1970, 1976).
44. Removed from *Lithophyllum pustulatum* f. *ascripticium* by Adey (1970); however, comparative studies of the remaining species of *Dermatolithon* (a probable synonym) and studies of Texas isolates are needed.
45. Removed to *Haliptylon subulata* by Johansen (1970).
46. Removed to *J. adhaerens* by Johansen (1971).
47. A herbarium mount collected in south Texas and labeled *J. adhaerens* (Hildebrand and Humm, Oct. 11, 1952) was examined and is *J. capillacea.*
48. Removed to *Solieria* and *Neoagardhiella* by Wynne and Taylor (1973). A herbarium mount labeled *A. tenera* (Hildebrand and Humm #161, Oct. 11, 1952) collected from the jetties was examined, and proved to be *Solieria tenera.*
49. A herbarium mount collected in south Texas and labeled *G. armata* (Hildebrand and Humm #179, Oct. 23, 1953) may be this species, but it is probably no longer present.
50. A herbarium mount collected in south Texas and labeled *G. caudata* (Hildebrand and Humm #176, Oct. 23, 1953) may be this species, but it is probably no longer present.
51. Listed as synonymous with *G. foliifera* by Taylor (1960).
52. Plants can be collected which conform to this species, but due to its polymorphic nature, and until further studies are done, are here referred to as *H. cornuta.*
53. A herbarium mount collected in south Texas and labeled *H. cervicornis* (Hildebrand and Humm #182, Oct. 23, 1953) is probably not this species, but it cannot be positively identified.
54. Listed by Taylor (1960) as synonymous with *L. baileyana.*
55. A herbarium specimen collected in south Texas and labeled *L. uncinata* (Hildebrand and Humm, Sept. 27, 1952) was examined, and is *L. baileyana.*
56. The identity of a herbarium mount collected in south Texas and labeled *C.*

corymbosum (Hildebrand and Humm, Oct. 11, 1952) is questionable; however, positive identification cannot be made. Kapraun (pers. comm.) suggests that *C. corymbosum* does not occur in the tropics, and records for this species probably refer to *C. cordatum*. Kapraun collected *C. cordatum* from Port Aransas. We, however, did not find it at South Padre Island.

57. Herbarium mounts collected in south Texas and labeled *P. ferulacea* (Hildebrand and Humm, Oct. 11, 1953) best conform to *P. havanensis*, as treated by Edwards (1970, 1976).
58. A herbarium mount collected in south Texas and labeled *P. hapalacantha* (Strawn and Humm, June 5, 1952) is most similar to *P. echinata*, but is difficult to identify postively.
59. A herbarium mount collected in south Texas and labeled *P. havanensis* is by current treatment, *P. gorgoniae*.
60. Plants with eight or more pericentral cells are tentatively placed in *P. tepida* by the authors. A herbarium mount collected in south Texas and labeled *P. howei* (Hildebrand and Humm. Aug. 16, 1957) is *P. tepida*.
61. Dr. Don Kapraun pointed out to us that Bliding (1968) states that *Ulva lactuca* is not found south of New England. Our "*Ulva lactuca*" conforms to the description of this genus and species; however, we agree that this plant must be examined more critically. For the present, we retain this identification.
62. *Spyridia hypnoides* (Bory) Papenfuss is synonymous with *Spyridia aculeata* (Schimp.) Kuetzing. *S. hypnoides* is our preferred name.
63. Kapraun (pers. comm.) found *P. macrocarpa* at Port Aransas in the summer of 1978.
64. This alga conforms to the description of *Porphyra leucosticta*; however, the the authors agree that specific assignment must await a more critical examination.

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TOXICITY AND BIOCONCENTRATION OF EPN AND LEPTOPHOS TO SELECTED ESTUARINE ANIMALS[1]

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ABSTRACT

Acute (96-hr) flow-through toxicity tests, chronic (entire life-cycle) tests, and bioconcentration studies were conducted on selected estuarine animals with the insecticides, EPN, and leptophos. In the EPN acute toxicity tests, the test animals and their 96-h LC50 values were: *Mysidopsis bahia*, 3.44 μg/l; *Penaeus duorarum*, 0.29 μg/l; *Cyprinodon variegatus*, 188.9 μg/l; *Lagodon rhomboides*, 18.3 μg/l; and *Leiostomus xanthurus*, 25.6 μg/l. Test animals and 96-h LC50 values for leptophos were: *M. bahia*, 3.16 μg/l; *P. duorarum*, 1.88 μg/l; and *L. xanthurus*, 4.06 μg/l. In separate chronic tests, *M. bahia* were exposed to EPN and leptophos. Significant ($\alpha = 0.05$) mortality and fewer young were produced in 4.13 μg/l EPN. In the leptophos chronic test, significant mortality occurred in concentrations ≥ 3.63 μg/l and fewer young were produced in concentrations ≥ 1.77 μg/l. *L. rhomboides*, exposed to EPN in a 26-day uptake study, bioconcentrated the insecticide 707 X that measured in the exposure water. When *L. rhomboides* were held in EPN-free seawater, no EPN was detected in their tissues after eight days. *L. xanthurus*, exposed to leptophos for 26 days, bioconcentrated the insecticide to only 68 × the concentration in the exposure water. No leptophos residues were detectable in tissues after 4 days depuration. Our results indicate that if either insecticide contaminated an estuarine environment in concentrations ≥ 1.0 μg/l, the most profound adverse effects on crustaceans and possibly fishes would result from acute toxicity, rather than from chronic toxicity or bioconcentration of the chemicals.

INTRODUCTION

In April 1977, the Environmental Research Laboratory, Gulf Breeze, Florida, was requested by the Environmental Protection Agency's Region VI to conduct toxicity and bioconcentration studies on the insecticides EPN and leptophos. The request was prompted by the detection of these chemicals in water, sediment, and biota adjacent to the Velsicol Chemical Company's Bayport Plant, Texas, and in oysters of nearby Galveston Bay.

Leptophos (Phosvel®; 4-bromo-2,5-dichlorophenyl phenylphosphonothioate) is manufactured in the United States and exported but not registered for use on crops in the U.S. except under provisions of a temporary permit on limited acreage.

The toxicity to or bioconcentration of leptophos by aquatic biota has been de-

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scribed in few published studies. In a 45-day study (Metcalf and Sanborn 1975), the fate of leptophos was determined in a model terrestrial-aquatic ecosystem. Results indicated that leptophos was accumulated 2 to 550 times greater in the fish and snails of the ecosystem than ten other organophosphate insecticides tested.

EPN (O-ethyl-o-p-nitrophenyl phenyl phosphonothioate) is registered for use on agricultural crops in the United States, and its acute toxicity to several freshwater organisms has been studied. The 96-h LC50 values reported for various species of freshwater fishes exposed to EPN ranged from 32 μg/l to 450 μg/l (Pickering *et al.* 1962); those for several freshwater invertebrates ranged from 0.06 μg/l to 7 μg/l (Crosby *et al.* 1966; Sanders 1972).

Acute toxicity data from studies on estuarine species were similar. The range in acute LC50 values for fishes was 60 μg/l (96-h) to 320 μg/l (48-h) (Korn and Earnest 1974; Schoettger 1970; and J. I. Lowe, Environmental Research Laboratory, Gulf Breeze, Florida, personal communication); the 48-h LC50 for the commercial pink shrimp (*Penaeus duorarum*) was 3.2 μg/l (J. I. Lowe, personal communication).

No LC50 value described above was based on flow-through tests and measured concentrations of EPN or leptophos in seawater. No study described the chronic toxicity of either insecticide to estuarine animals or the accumulation of the insecticides in the animals' tissues. Our research sought to determine: (1) the acute toxicity of EPN and leptophos to several estuarine species based on measured concentrations of the insecticides in flowing seawater; (2) the accumulation of the insecticides in flowing seawater; (2) the accumulation of the insecticides in tissues of animals surviving a 96-h test; (3) the chronic (entire life cycle) toxicity of leptophos and EPN to the estuarine mysid, *Mysidopsis bahia*; and (4) the uptake rates, depuration rates, and bioconcentration factors of EPN using pinfish (*Lagodon rhomboides*) and leptophos using spot (*Leiostomus xanthurus*).

METHODS AND MATERIALS

Test Animals

All test animals, except mysid shrimp (*M. bahia*), used in 96-h toxicity tests, were collected in estuarine waters near the Environmental Research Laboratory, Gulf Breeze, Florida. Mysids were cultured in the laboratory following the methods of Nimmo *et al.* (1977). The animals were used in the toxicity test if mortality was less than 1% in the preceding 48 h and if they exhibited no obvious diseases or abnormal behavior during acclimation. No animals were fed during toxicity tests except the mysid shrimp that were fed brine shrimp (*Artemia salina*) nauplii *ad libitum*.

Juvenile pinfish and spot were used in separate EPN and leptophos bioconcentration studies, respectively. The fish were collected from estuarine areas near the laboratory and acclimated to laboratory conditions at least 14 days prior to testing. Criteria used to determine acceptable test animals were the same as those for the acute toxicity tests. Fishes were fed frozen adult brine shrimp at 10% body weight per day; no EPN (< 0.02 mg/kg) or leptophos (< 0.025 mg/kg) was detected in brine shrimp by electron-capture gas chromatography.

Mysid shrimp, used for the 21- or 28-day entire life-cycle tests, were produced from laboratory cultures. Mysids were fed live brine shrimp nauplii *ad libitum* each day.

Acute Toxicity Tests

Methods used in the acute toxicity tests, except in the case of mysids, followed the flow-through toxicity test procedures of the American Public Health Association (1975). The only modification of methods was the feeding of brine shrimp nauplii to mysids to prevent starvation during the 96-h period. The acute toxicity of EPN or leptophos was determined by exposing 20 animals per aquarium to each concentration for 96 h. Analytical grade EPN (97.2%) or leptophos (98%) was dissolved in triethylene glycol (TEG) and metered by pumps at 10 ml per day into the filtered seawater that entered each aquarium from siphons calibrated to deliver 30 l/h. One control aquarium received the same quantity of seawater and solvent with no insecticide; the second received only seawater at 30 l/h. Mortality was recorded daily, and dead animals were removed when discovered. Fishes and pink shrimp surviving the tests were rinsed with acetone and analyzed for whole-body residues.

Toxicity tests with mysids, because of their small size, required several modifications in the above procedures. We placed five animals (24-h-old juveniles) in each of four replicate chambers (10 cm × 15 cm) in each test concentration, using the methods of Nimmo *et al.* (1977). Seawater flow for the leptophos studies was delivered by a diluter at the rate of 3.7 l/h. Surviving animals were not analyzed for residues.

Mysid Entire Life-Cycle Studies

Mysid shrimp were exposed to EPN or leptophos in two separate studies, using the methods of Nimmo *et al.* (1977). The leptophos test was conducted using a diluter (Mount and Brungs 1967); the EPN test, syringe pumps and calibrated siphons (Nimmo *et al.* 1977). Two controls were provided for the EPN test (seawater with and without the carrier, TEG, at 0.05 ml/l). In the leptophos study, control seawater with 0.05 ml/l TEG was provided. In the EPN study, nominal concentrations were : 3.0, 0.3, 0.1, and 0.075 μg/l. Those for the leptophos study were: 5.0, 2.5, 1.3 and 0.63 μg/l. As each aquarium achieved maximum volume, a self-starting syphon drained the water to a volume of approximately one liter. Fluctuating levels of seawater, occurring at about 30 minute intervals, ensured an exchange of seawater within each aquarium and small retaining chambers (a Petri dish bottom to which a 15 cm high nylon mesh collar was attached). A small stream of compressed air was delivered into each chamber to safeguard against possible anoxic conditions and to create a current that apparently aids in the orientation of the test animals.

Approximately forty 48-h old juveniles (4 or 5 per chamber) were exposed to each concentration of EPN or leptophos for a period of 28 to 21 days, respectively. During this exposure period, juvenile mysids mature and produce at least one brood. Number of live animals by sex, number of females with and without brood pouches, and number of young were recorded daily; dead animals were removed when observed.

Fish Bioconcentration Studies

Juvenile pinfish (44–77 mm standard length; $\bar{x} = 59$ mm) were exposed to EPN or 26 days followed by an 8-day depuration period. The exposure apparatus was the same used by Schimmel *et al.* (1977a). A stock solution of EPN dissolved in TEG was prepared at the beginning of the test and calculated deliveries were 0.25 and 2.5 μgEPN/l seawater. Each exposure concentration was duplicated; two control aquaria were provided, one with and one without TEG. We selected these concentrations because: (1) acute toxicity studies indicated that they were well below the EPN lethal threshold for pinfish; and (2) they were quantifiable in gas chromatographic analyses.

Thirty juvenile pinfish were placed in each experimental and control aquarium at the beginning of the test. Two fish from each control, 0.25 and 2.5 μg/l aquarium were sampled for bioconcentration at 24, 48, and 96 hours, and days 8, 15, 18 and 22. The chemical exposure was terminated after 26 days and remaining fish were held in EPN free seawater and sampled on days 1,2,4, and 8. Tissues were analyzed on a whole-body wet-weight basis. Seawater temperature averaged 25°C (range = 23 to 28°C); seawater salinity averaged 25.7 ‰ (range = 22 to 31 ‰).

Juvenile spot were exposed to leptophos for 26 days followed by a 4-day depuration period. The exposure apparatus (Schimmel *et al.* 1977a) was the same as that used in the EPN study. A stock solution of leptophos, dissolved in TEG, was prepared at the beginning of the test. Experimental concentrations delivered were 0.04 and 0.4 μg/l. Each exposure concentration was duplicated and two control aquaria were provided, one with and one without TEG. The concentrations selected were based on the same criteria as the EPN test.

Fifty juvenile spot were placed in each exposure aquarium at the beginning of the test. Three fish (pooled) from each control, 0.04 and 0.4 μg/l aquarium were sampled at 24 and 96 h, and twice each week thereafter for 26 days. After 26 days, the chemical exposure was terminated and remaining fish were held in leptophos free seawater. Each fish was dissected into edible tissues (muscle and skin without scales taken from each side of the fish above the lateral line) and remaining tissues (all portions minus the edible tissues). In the depuration period, fish were sampled at 24-, 48-, 72- and 96-h.

Statistical Methods

Shrimp and fish mortality data from acute toxicity tests were analyzed by using the probit analysis method of Finney (1971) to estimate concentrations of EPN and leptophos in water that killed 50% of the test animals (LC50), and the 95% confidence intervals for these concentrations.

In the mysid entire life-cycle studies, LC50 values (and 95% confidence intervals) for the 21- and 28-day exposures were calculated by the probit analysis of Finney (1971). We used Dunnett's test, comparing multiple treatments with control to mean brood size and analysis of variance with Student-Newman Keuls' *post hoc* test to determine significant differences in mortality of experimental and control mysids. Significant levels of 95% were used for all statistical calculations.

In the bioconcentration studies, the statistical model of Bahner and Oglesby (1978) was used to determine bioconcentration factors and to describe uptake and depuration of EPN and leptophos in pinfish and spot.

Chemical Methods

In the analysis of tissue samples for EPN and leptophos, one to eight grams of tissue were weighed into 150 mm × 25 mm (O.D.) screw-top test tubes and extracted four times with 5 ml portions of acetonitrile for 30 seconds using a model PT 10-ST Willems Polytron®. The test tube was centrifuged after each extraction and the acetonitrile transferred to a 120-ml oil sample bottle. To the combined extracts was added 75 ml of 2.0% aqueous sodium sulfate, and this solution was extracted with four 5 ml portions of hexane. The bottle was capped and shaken for one minute, the solvent phases allowed to separate, and the upper hexane layer pipetted into a 25 ml Kuderna-Danish concentrator tube. The combined extracts were then concentrated to 0.5 ml on a steam table with a micro Snyder column. The concentrate was quantitatively transferred with three 0.5 ml portions of hexane to a 9 mm Chromaflex column (Kontes Glass Company, Vineland, N.J.) containing 3.0 grams of Florisil topped with 2.0 grams anhydrous sodium sulfate that had been washed previously with 10 ml hexane.

For the analysis of EPN, the column was first eluted with 20 ml of 5% diethyl ether in hexane to remove PCB's and pesticides; EPN was then eluted with 25 ml of 10% isopropanol in iso-octane and the volume adjusted to the appropriate level for analysis by electron-capture gas chromatography.

For leptophos, the column was eluted with 20 ml of 5% diethyl ether/hexane solution and the volume was adjusted to an appropriate level for analysis by electron-capture gas chromatography.

One liter of seawater samples were fortified with heptachlorobiphenyl for EPN analysis and methyl parathion for leptophos analysis and extracted twice with 100 ml petroleum ether. The solvent extract was dried and concentrated to an appropriate volume on a steam table using a Kuderna-Danish concentrator.

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TABLE 1

Acute (96-hr) toxicity of EPN and lepthophos to several estuarine animals in flowing seawater tests.

INSECTICIDE	SPECIES	LENGTH[a] ($\bar{x}$,mm)	MEASURED CONCENTRATIONS LC50 in µg/ℓ (95% confidence interval)	TEMPERATURE ($\bar{x}$, °C)	SALINITY ($\bar{x}$, °/oo)
EPN	Estuarine mysid *(Mysidopsis bahia)*	7.5	3.44 (2.49 - 5.84)	23.5	24.0
	Pink shrimp, *(Penaeus duorarum)*	69	0.29 (0.1 - 1.1)	25.0	22.0
	Sheepshead minnow, *(Cyprinodon variegatus)*	41	188.9 (150.0 - 255.2)	24.6	18.2
	Pinfish, *(Lagodon rhomboides)*	64	18.3 (14.7 - 23.5)	25.0	28.8
	Spot, *(Leiostomus xanthurus)*	51	25.6 (19.2 - 34.2)	24.0	23.2
LEPTOPHOS	Estuarine mysid *(Mysidopsis bahia)*	2	3.16 (1.89 - 5.67)	25.0	16.0
	Pink shrimp, *(Penaeus duorarum)*	---	1.88 (1.48 - 2.36)	27.1	27.2
	Spot, *(Leiostomus xanthurus)*	35	4.06 (3.65 - 4.71)	22.5	23.1

[a]Mysids, total length; pink shrimp, rostrum to telson length; fishes, standard length.

Analysis for EPN were performed on Hewlett-Packard Model 5730A electron-capture (^{63}Ni) gas chromatographs equipped with 182 cm × 2 mm (I.D.) glass columns packed with 2% SP 2100 on 100/120 mesh Supelcoport, 0.75% SP 2250; 0.97% SP 2401 on 100/120 mesh Supelcoport or 5% QF-1 on 80/100 mesh Gas Chrom Q. The operating parameters were: oven temperature 210°C; injector temperature, 200°C; detector temperature, 300°C; carrier gas, 10% methane/argon flowing at 25 ml/minute.

Analysis for leptophos in tissue and seawater were performed on a model 5710 Hewlett-Packard Gas Chromatograph with the columns and operating parameters as those used for EPN analyses.

Calculations for EPN and leptophos were made on a wet-weight basis without a correction factor for percentage recovery. The recovery values for EPN and leptophos from fortified tissues and seawater were greater than 85%.

RESULTS

Results of acute EPN and leptophos toxicity tests with mysids, shrimp and fishes are shown in Table 1. From these data, crustaceans are particularly sensitive to the two insecticides; pink shrimp were the most sensitive with 96-h LC50 values of 0.29 and 1.88 µg/l for EPN and leptophos, respectively. Sheepshead minnows were relatively insensitive to leptophos with a 96-h LC50 of 188.9 µg/l.

Survivors of the 96-h toxicity tests were analyzed for EPN and leptophos residues. The test animals and their average bioconcentration factors for EPN after a 96-h exposure were: pink shrimp, non-detectable (< 0.02 mg/kg); spot 260 ×; and pinfish, 774 ×. Average bioconcentration factors for pink shrimp and spot exposed to leptophos for 96 hours were 530 × and 222 ×, respectively.

Mysid Entire Life-cycle Studies

Results of entire life-cycle exposures of mysids to EPN and leptophos are shown in Tables 2 and 3. These data show that both insecticides exhibited toxic

TABLE 2.

Toxicity of EPN and leptophos to *Mysidopsis bahia* in two life-cycle exposures. Test duration for the EPN study was 28 days; for leptophos, 21 days.

INSECTICIDE	MEASURED CONCENTRATION (µg/ℓ)	%MORTALITY	NO. YOUNG/FEMALE
EPN	0.0	10	16.1
	0.0	3	14.6
	0.067	0	18.5
	0.076	8	14.8
	0.44	8	15.9
	4.13	68*	3.5*
LEPTOPHOS	0.0	12	5.1
	0.64	24	7.4
	1.77	24	2.2*
	3.63	54*	0*
	5.63	74*	0*

*Significantly different from control at $\alpha = 0.05$.

TABLE 3.

Summary of acute and entire life-cycle exposure of *Mysidopsis bahia* to EPN and leptophos.

INSECTICIDE	96-hr LC50 (95% Confidence Interval)	MATC*, µg/ℓ (Geometric Mean)	A.F.** (Geometric Mean)
EPN	3.44 (2.49 - 5.84)	0.44 - 4.13 (1.35)	0.13 - 1.2 (0.40)
LEPTOPHOS	3.16 (1.89 - 5.67)	0.64 - 1.77 (1.06)	0.20 - 0.56 (0.33)

*MATC = Maximum Acceptable Toxicant Concentration; Mount and Stephan 1967.
**A.F. - Application Factor; the ratio of the MATC to the 96-hr LC50.

effects on mysids at low concentrations. In the EPN study, mysids exposed to 4.13 µg/l suffered significantly greater ($\alpha = 0.05$) mortality and produced fewer young per female than the control mysids (Table 2). In the leptophos study mysids exposed to concentrations ≥ 3.63 µg/l suffered significant mortality and in the 1.77 µg/l concentration produced fewer young per female than the control mysids. The geometric mean of the Maximum Acceptable Toxicant Concentration (MATC, Mount and Stephan, 1967) and the lowest concentration producing adverse effects with both EPN and leptophos are approximately 0.3 × their respective 96-h LC50 (Table 3). Therefore, the acute toxicity of EPN and leptophos to mysids is a relatively close estimate of chronic toxicity.

Bioconcentration Studies

Pinfish exposed to 2.4 µg/l EPN (measured concentration) bioconcentrated the insecticide rapidly and reached an apparent equilibrium in approximately

48 h (Fig. 1). Uptake/depuration data for the 0.17 μg/l concentration (0.25 μg/l, nominal concentration) were not illustrated because residues in these tissues were usually below the level of detectability (0.02 mg/kg). At equilibrium (plateau) the concentration of EPN in whole pinfish was approximately 1.7 mg/kg giving a bioconcentration factor (BCF; concentration of EPN in fish tissues divided by the measured concentration of EPN in exposure water) of 707 X. By comparison, pinfish exposed to EPN for 96 h in the acute study, bioconcentrated an average of 744 X.

After a four-day post exposure period, only one pinfish of four sampled had detectable (0.041 mg/kg) EPN in its tissues; after eight days, no residues were detected in any fish sampled.

Spot exposed to 0.61 μg/l measured concentrations (0.4 μg/l nominal) of leptophos bioconcentrated the insecticide to an apparent equilibrium of 0.04 mg/kg in their remaining tissues (Fig. 2). No residues were found in edible tissues above the detectable limit (0.025 mg/kg). In addition, no detectable residues were found in fish exposed to 0.04 μg leptophos/litre seawater. The BCF of leptophos at equilibrium for spot was 68 ×. After a 4-day post exposure period, no leptophos was detected in tissues. By comparison, spot exposed to leptophos for 96 h in the acute study bioconcentrated an average of 22 ×. The higher average BCF in the acute study appears to conflict with the results of the 26-day study. However, the BCF at 0.78 μg/l concentration (the exposure concentration in the acute test closest to the 26-day study, 0.6 μg/l) was 86 ×. In general, the BCF appeared to be directly related to exposure concentration.

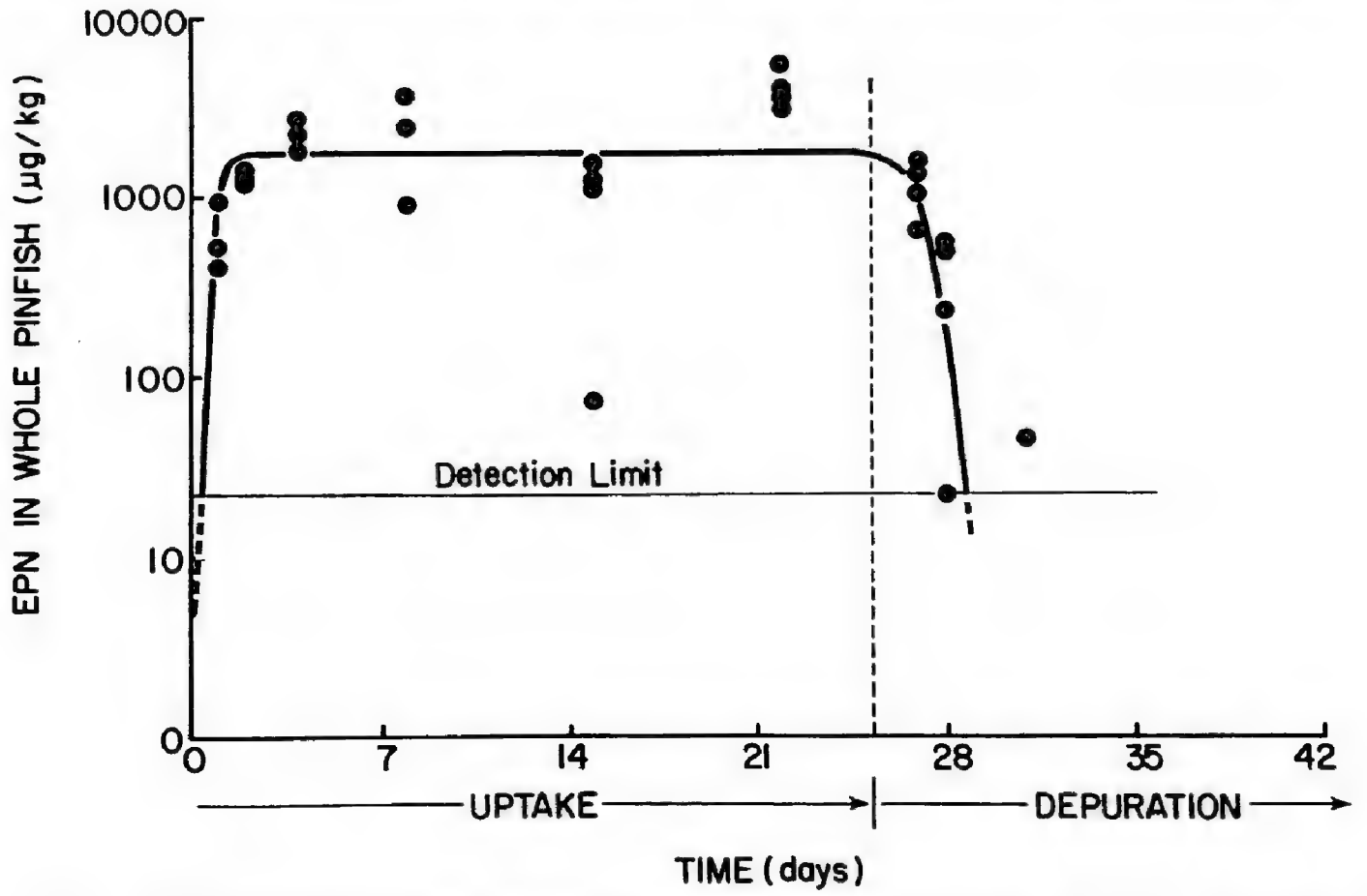

FIG. 1. Uptake and depuration of EPN in whole-body tissues of pinfish (*Lagodon rhomboides*) in a flowering seawater bioassay. Exposure concentration average 2.4 μg=l EPN per liter seawater.

DISCUSSION

Our 96-h EPN acute toxicity test results reported are comparable to those reported for freshwater species. Sanders (1972) reported 96-h LC50 values of 6.8 and 0.56 μg/l for scud (*Gammarus fasciatus*) and glass shrimp (*Palaemonetes kadiakensis*), respectively. Pickering *et al.* (1962) reported the 96-h LC50 values of EPN for several freshwater fishes: bluegill (*Lepomis macrochirus*), 100 μg/l; fathead minnows (*Pimphales promelas*), 250 μg/l; goldfish (*Carassius amatus*), 450 μg/l; and guppies (*Lebistes reticulatus*), 32 μg/l. Korn and Earnest (1974) exposed juvenile striped bass (*Morone saxatilis*) to EPN in flowing seawater and calculated a 96-hour LC50 of 60 μg/l. Our data on spot (LC50 = 25.6 μg/l) and pinfish (18.3 μg/l) show that these species are more sensitive than freshwater fishes; sensitivity of sheepshead minnows to EPN (LC50 = 189 μg/l) was comparable to those of fathead minnows and bluegills.

The data from the pink shrimp exposure to EPN are cause for particular concern. Shrimp were especially sensitive to EPN (LC50 = 0.29 μg/l), and there was even 20% mortality among shrimp exposed for 96 hours to a non-detectable concentration (0.032 μg/l, nominal). Further, since no EPN was detected in tissues of shrimp exposed to concentrations as high as 0.42 μg/l, it is conceivable that pink shrimp in estuarine habitats could suffer significant mortality if exposed to EPN for greater than 96 hours to concentrations below detection limits (0.02 μg/l) and the identity of the toxicant causing the mortality could not be determined by residue analysis.

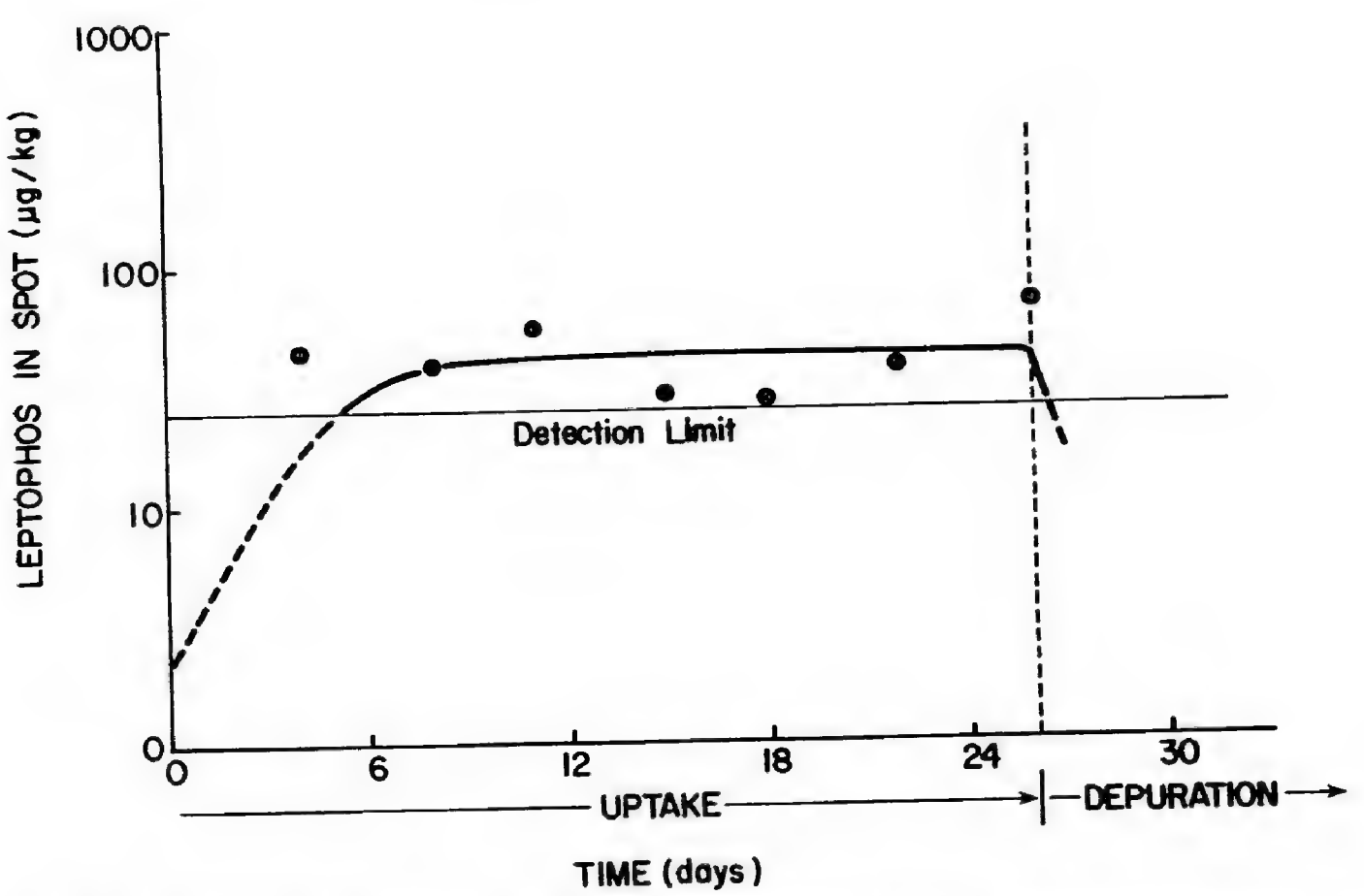

FIG. 2. Uptake and depuration of leptophos in tissues of spot (*Leiostomus xanthurus*) in a flowing seawater bioassay. Exposure concentration averaged 0.61 μg leptophos per litre seawater.

We found no leptophos acute toxicity data on fishes or aquatic invertebrates in the literature which could be compared with our values.

Results of the mysid chronic studies with EPN and leptophos indicate that the geometric means of the MATC's for each insecticide were 1.35 and 1.06 μg-l, respectively, giving application factors of 0.40 for EPN and 0.33 for leptophos. We are unaware of any published data which describe the chronic toxicity of EPN or leptophos to any other estuarine species. However, a leptophos 28-day embryo/larval study was conducted on sheepshead minnows. No significant effects ($\alpha = 0.05$) on survival were noted in fish exposed to concentrations as high as 15 μg/l; however, significant effects on growth occurred in 28 days (Larry R. Goodman, Environmental Research Laboratory, Gulf Breeze, Florida; personal communication). Results of the mysid studies and the sheepshead minnows embryo/larval studies indicate that chronic effects are not anticipated at concentrations much less than 0.3 × the 96-hr LC50. By comparison, Kepone® (an organochlorine insecticide) produced deleterious effects in sheepshead minnow embryo/larval study indicate that chronic effects are not anticipated at reproduction in mysids at 0.04 × the 96-h LC50 of 10.1 μg/l (Nimmo *et al.* 1977).

From our studies, the bioconcentration factors (BCF) and depuration rates of EPN and leptophos indicate that the insecticides would not accumulate to high concentrations in the aquatic food web. In the event of aquatic contamination, both insecticides should depurate quickly. Our data on leptophos appear to conflict with those of Metcalf and Sanborn (1975) who studied the insecticide in a terrestrial-aquatic model ecosystem. Their aquatic system was dosed with a single application of ^{14}C-labeled leptophos and the distribution of the insecticide was monitored at the end of 45 days. Bioconcentration factors for the plants and animals were based on measured concentrations of leptophos in water at the end of the test. If the pesticide in water disappeared with time, we feel that concentrations at 45 days may overestimate the bioconcentration factors. Therefore, no real comparison of our data and those of Metcalf and Sanborn (1975) can be made.

Bioconcentration factors of 707 for EPN and 68 for leptophos which we determined in our study are far below those for fishes exposed to most organochlorine insecticides. For example, endosulfan was bioconcentrated by mullet 2755 × in 28 days (Schimmel *et al.* 1977a); heptachlor was bioconcentrated by spot 3,600 × and trans-chlordane 4,600 × in 24 days (Schimmel *et al.* 1976). However, the bioconcentration factor for BHC in pinfish (180 × in edible tissues, 617 × in offal; Schimmel *et al.* 1977b) was similar to those reported in this paper.

In summary, both EPN and leptophos were acutely toxic to both crustaceans and fishes, the commercial pink shrimp was the most sensitive species tested with 96-h LC50 values of 0.29 μg/l for EPN and 1.88 μg/l for leptophos. In chronic studies with mysid shrimp, both EPN and leptophos exhibited adverse effects at concentrations of approximately 0.3 × the 96-h LC50 indicating that acute toxicity is a relatively close estimate of chronic toxicity. In two bioconcen-

tration studies, EPN and leptophos were taken up rapidly by two estuarine fishes to equilibrium in two to four days with bioconcentration factors of 707 × and 68 ×, respectively. After eight days in EPN-free seawater, no EPN was measured in pinfish tissues; no leptophos was measured in spot tissues after four days in leptophos-free seawater. Our data indicate that if EPN or leptophos contaminated estuarine environments in concentrations ≥ 1.0 μg/l, the most deleterious effect on crustaceans and possibly fishes would result from acute toxicity, not chronic toxicity or bioconcentration of the insecticides.

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DEPOSITIONAL HISTORY AND RATE OF DEPOSITION OF A FLOOD-TIDAL DELTA, CENTRAL TEXAS COAST

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ABSTRACT

^{14}C dating of shells from Harbor Island, a flood-tidal delta complex on the Central Texas coast, indicates that basal barrier island sand began accreting 6300 years ago at about 10 meters below present sea level. By 4900 years B.P., with sea level about 6 meters below present, a bay developed behind the barrier, and bay mud deposition proceeded at the rate of 2.4 meters per thousand years. 3400 years ago sea level in this area was about 2 meters below present. At that time the tidal delta facies that compose the present surface of the Harbor Island complex began to accrete at the rate of 0.06 meters per thousand years.

INTRODUCTION

Harbor Island is a broad, flood-tidal delta complex on the south-central Texas coast (Fig. 1). Initially, the island developed as a fan-shaped system of submerged sand shoals along the lagoonal (western) end of the tidal inlet, Aransas Pass. As the inlet migrated southward, the associated flood delta also accreted laterally. Localized "low energy shadows" formed bayward of these inlet mouth bars and became centers for the growth of submerged grassflats. The grassflats baffled tidal currents and produced effective traps for the continued vertical and horizontal accretion of sediment. As sediment accumulation progressed, the shoals developed into low, sandy marsh lands and tidal flats. The present day Harbor Island covers an area of 50 square kilometers and has an average elevation of < 1 meter.

In order to establish a time-sequence for the depositional history of Harbor Island and to estimate the rates of vertical accretion of sediment in the various facies, selected shell samples were radiocarbon-dated. Stable carbon and oxygen isotopic ratios of the shell carbonates were also determined to assess the effect, if any, of different environments on the isotopic composition of the shells. Finally, the ^{14}C ages from this study have been compared with previously published data and sea level curves from adjacent areas to further document Holocene sea level changes for this part of the Gulf of Mexico.

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SAMPLING PROCEDURE AND ANALYTICAL METHODS

Samples were collected from various horizons in cased jet-down borings (Munson 1975, p. 7) by M. Munson during the summer of 1974. ^{14}C measurements were made at the Radiocarbon Laboratory, Balcones Research Center, the University of Texas at Austin. Age calculations are based on a ^{14}C half-life of 5568 years, using NBS (National Bureau of Standards) 95% oxalic acid as a modern standard. Deviations reported are based on counting statistics of the sample, background and standard, and are $\pm 1\sigma$. The laboratory uses liquid scintillation counting of benzene, with Li_2C_2 and a vanadium-activated catalyst in preparation; chemical yields average 94%. Carbon and oxygen isotope ratios were determined by standard phosphoric acid procedures (McCrea 1950); machine-corrected data are reported relative to the PDB (belemnite carbonate) standard.

Validity of ^{14}C Dates and Sources of Error

Dates obtained by radiocarbon analysis of peat, algal mat and shell samples from various sites and facies within the Holocene of the Texas coast and southwestern Louisiana show a considerable range in age at specific stratigraphic positions, and in stratigraphic position (relative to present sea level) at particular ^{14}C ages (Fig. 2). Beside the fact that the samples came from different locations which have had different rates of deposition and depositional histories, anomalous ages can occur within a single stratigraphic section, and errors can be introduced during the sampling procedure.

Some anomalously old ages result from natural processes of sedimentation such as the reworking of shallow marine beds by wave action and the shifting of wood or shell particles to modern beaches. Anomalous ages may also result from diagenetic changes such as the leaching of aragonitic shells or their exchange with older carbon through the action of groundwater. In addition, living organisms can incorporate old carbon into the shell material that they secrete and thus give rise to anomalous ages. In dating material from drill or jet-down holes, contamination of cuttings by caving from up-hole may give rise to anomalously young ages. Since contamination from above is often impossible to detect, it must be assumed that the youngest date obtained from a group of samples taken at a given point is more accurate for geologic purposes than are older dates.

Through dating of various molluscan genera from the same samples, it has been established that the larger, more durable shells such as *Crassostrea virginica* are commonly much older than are the smaller, more delicate shells such as *Mulinia lateralis* (Gould and McFarlan 1959). This suggests that the larger shells are more often reworked from older deposits than the smaller shells. Thus, in dating shell samples, we restricted determinations wherever possible to the smaller fragile forms which showed no signs of reworking.

One of the most important aspects to consider in using radiocarbon-dated samples to establish rates of sedimentation and paleo-sealevel is the probable depth (or elevation above sea level) at which the sample material grew and was deposited (assuming that it has not been reworked) Marine peat and algal mats generally occur within restricted ranges relative to sea level. Peat forms in an intertidal salt marsh environment; thin beds do not undergo appreciable compaction, so it can be assumed that shallow peat samples accumulated at about mean sea level (Scholl, Craighead and Stuiver 1969) to —0.5 meters (Gould and McFarlan 1959). Algal mats occur on tidal and wind-tidal flats adjacent to lagoons at elevations of 0 to less than 1 meter above sea level (Brown, Fisher, Erxleben and McGowen 1971). Molluscs, on the other hand, can live at widely-varying depths. It is therefore necessary to determine the facies in which a shell sample occurs and the dominant genera present in order to substantiate a depth range. On the Texas coast, grassflat facies occur in water depths of 0.3 to 1.5 meters; the average depth of lagoons and small open bays is 2 meters (Brown *et al.* 1971). Most living oysters occur near or on the crests of oyster reefs, just below the mean low tide level, but oysters may grow at depths of 1 to 2 meters below sea level. Barrier island sands and tidal inlet facies extend to depths greater than 9 meters; if shell samples from these zones are not located near their upper or lower boundaries (so that water depth at the time of deposition may be estimated from adjacent facies) it is difficult to establish an accurate depth for these samples. Thus peat

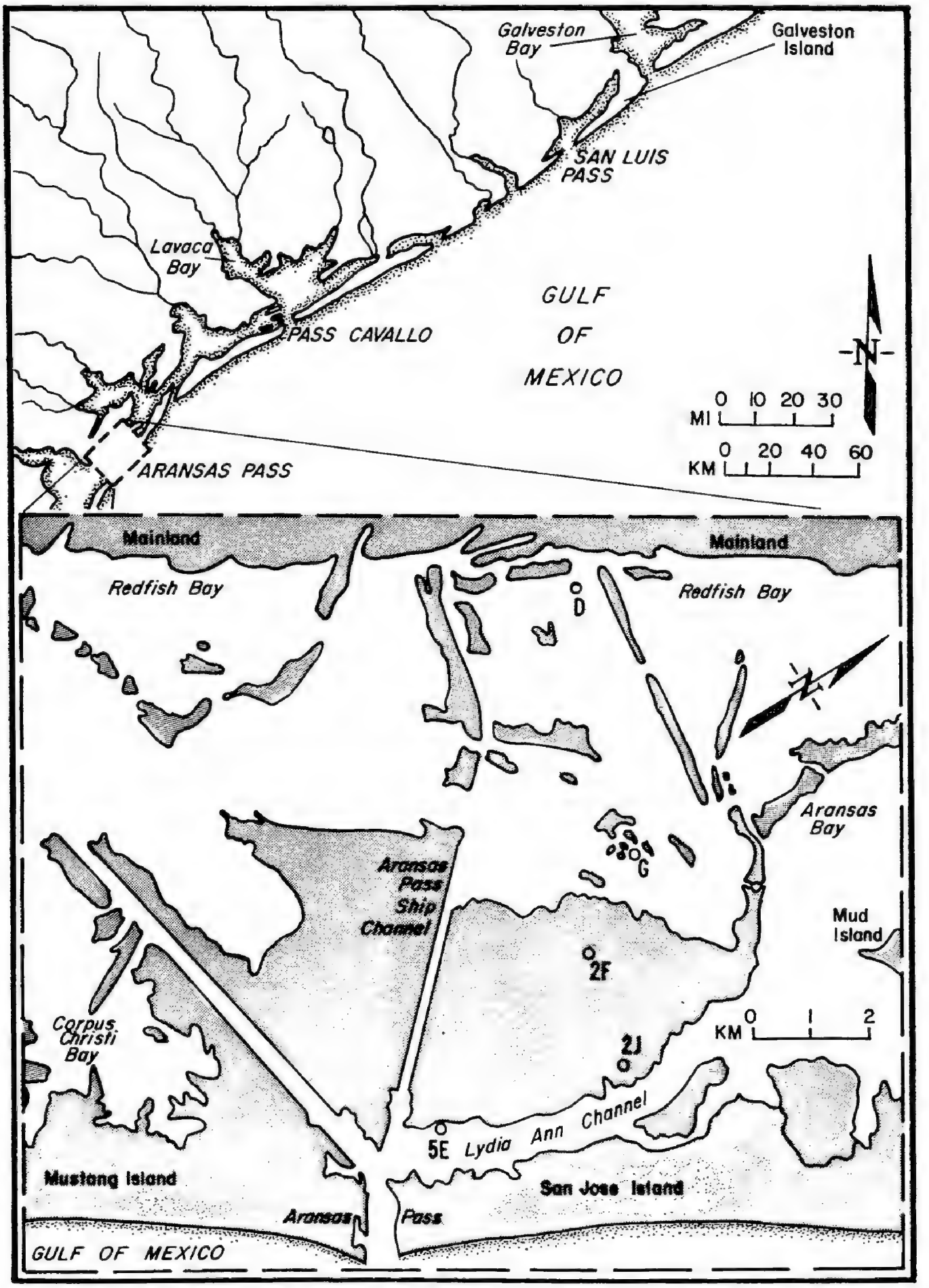

FIG. 1. Texas Gulf coast showing locations of study area and location of Harbor Island sample sites (adapted from Munson 1975).

and algal mat are often more reliable for locating and dating paleo-sealevel than are shell and wood fragments. The shell samples used for dating in this study were carefully selected for the most accurate estimation of their depth relative to sea level at the time of burial.

RESULTS

Depositional History

About 6000 years ago barrier islands began to develop in or near their present positions along the Texas coast (Fisk 1959; Bernard Leblanc and Major 1962; Wilkinson 1975). Sample Tx-2310, from the base of a clean, well-sorted sand unit 10.4 meters below present sea level (site 5E, Fig. 3), represents the initial sand deposition under Harbor Island. The sand contains a Gulf-shoreface faunal assemblage and was probably deposited as back-island sediment along the bay side of a transgressing, narrow, low-profile sand shoal (Munson 1975, p. 91). Three fractions from sample Tx-2310 were dated: A). clean, delicate white *Mulinia lateralis* shells; B). blackened mixed shells, consisting mostly of *Mulinia lateralis* and *Donax variabilis*; and C). echinoderm (*Mellita* sp.) fragments. The ^{14}C ages of the three fractions are 6320 ± 230 years B.P.; 9740 ± 140 years B.P.; and 7260 ± 150 years B.P. (Table 1). The ages of both Tx-2310-A and Tx-2310-C fall within the range of published sealevel curves (Fig. 2). The echinoid fraction may have been reworked, because *Mellita* usually inhabits quiet, lower shoreface sandy bottoms where the molluscan genera in this sample do not occur; reworking would account for the greater age of Tx-2310-C than Tx-2310-A. The blackened fraction, Tx-2310-B, is clearly too old for its stratigraphic position. The shells in this fraction appeared more weathered than those in the other two fractions, and the insoluble residue from these shells consisted of very fine, filamentous black organic matter, which probably gives the shells their color. The black shell fraction probably represents material reworked from older, submerged deposits. The presence of organic material suggests that these shells may have passed at some stage through an organic-rich environment such as a marsh, grassflat or back-barrier pond.

The 6320 ± 210 years B.P. age of Tx-2310-A and its depth correspond with Wilkinson's (1973) date of 5750 years B.P. for first sand deposition under Matagorda Island (Fig. 1) at 9.5 to 11 meters below present sea level. Shepard and Moore (1955) dated initial sand deposition under San Jose Island, 13.9 meters below sea level, at 6400 years B.P.

Between 6300 years B.P. and 3400 years B.P. an open bay, inlet-influenced mud facies was deposited behind the sand shoal. Sample Tx-2311, from a horizon 7.0 meters below sea level at a site 1 km. landward of site 5E (Fig. 3), is composed of sediment from the lower portion of this facies. The sample consists of dark gray mud to muddy sand and it contains a bay faunal assemblage, dominated by *Lucina multilineata* and *Balanus* Sp. (Munson 1975, p. 66). The age of this sample is 5530 ± 90 years B.P.

By 4900 years B.P. a barrier island sand nucleus had been firmly established, partially restricting the bay behind it. Sample Tx-2333 (from the same boring as Tx-2310) is from the top of this unit, 5.8 meters below present sea level. Its age of 4840 ± 70 years B.P. gives an average rate of sand deposition of 3.1 meters per thousand years. Sample Tx-2312, from a boring 3 km. landward of Tx-

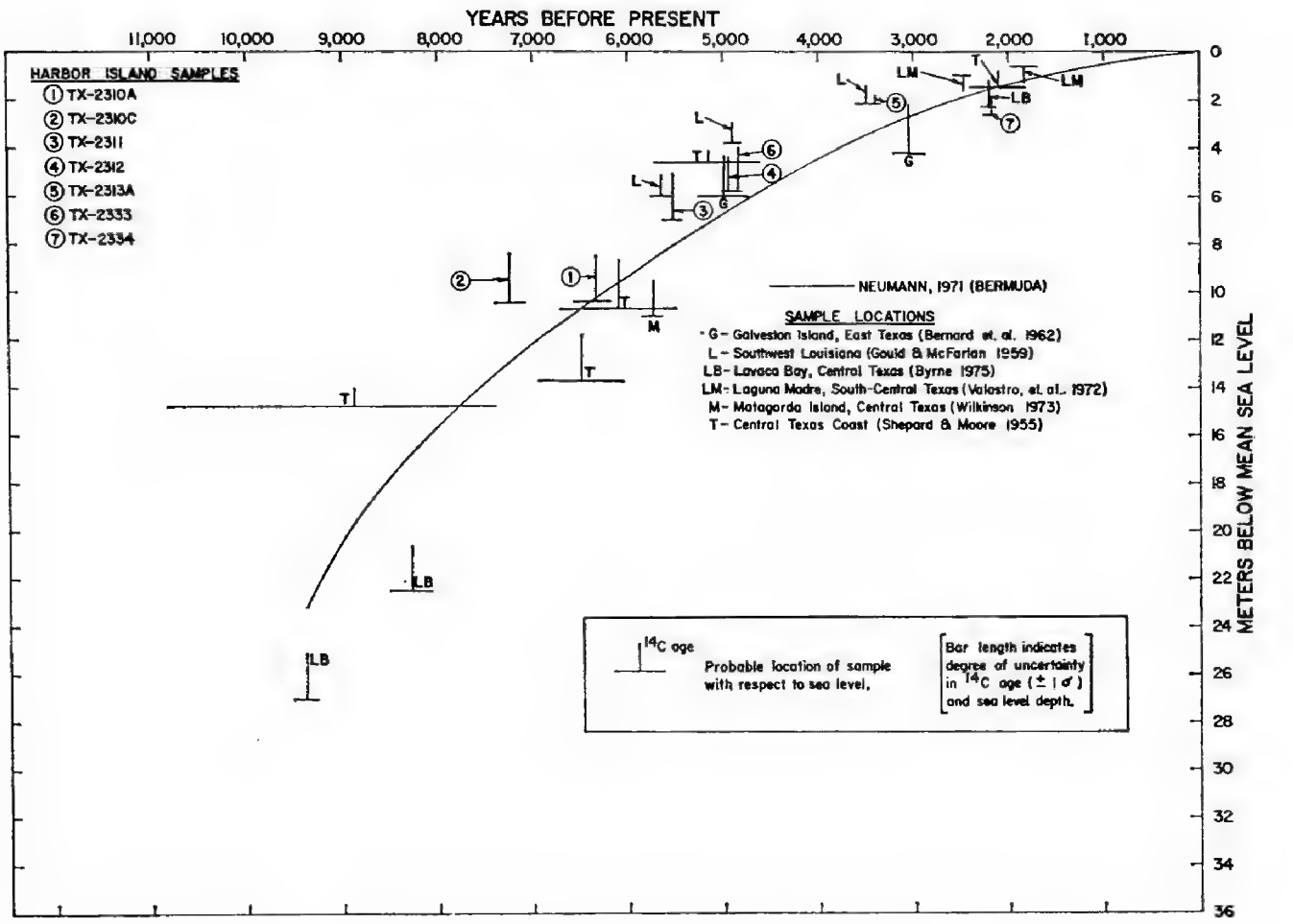

FIG. 2. Upper panel: Published sea level curve with ^{14}C age and sea level depths for samples taken along the Texas Gulf coast. Lower panel: Published sea level curves.

2333 (Fig. 3, site 2F), was retrieved from the base of the open-bay mud facies, 5.8 meters below present sea level. This sample, 4950 ± 60 years old, is correlative with Tx-2333, and it indicates the extent to which marine sediments had then transgressed the Pleistocene unconformity.

Deposition of open-bay mud continued until about 3400 years B.P., when the rate of sea level rise decreased substantially (Scholl *et al.* 1969; Neuman 1971). The average rate of deposition of bay mud between 4950 years B.P. and this time was 2.4 meters per thousand years (Shepard and Moore 1955, calculated an average rate of deposition of 2.3 meters per thousand years in lower San Antonio Bay, just north of the study area). As the rate of sea level rise decreased, shoaling became more extensive and the bay shallower and more restricted. A grassflat facies began to develop on the landward edge of the bay and grow out toward the bay center, while tidal-delta sand was deposited at the Gulfward (eastern) edge of the bay. Sample Tx-2313, 3410 ± 70 years old, is from the base of the grassflat facies, 2.1 meters below present sea level. The sediment consists of dark greenish-gray, poorly-sorted muddy sand, with abundant *Thalassia* fragments with a *Modulus modulus-Cerithidea pliculosa* faunal assemblage (Munson 1975), characteristic of modern shallow bay grassflat environments. Most of the sediments on Harbor Island above 2 meters below sea level are representative of this facies.

Continued shoaling produced by flood-tidal delta deposition from the east and

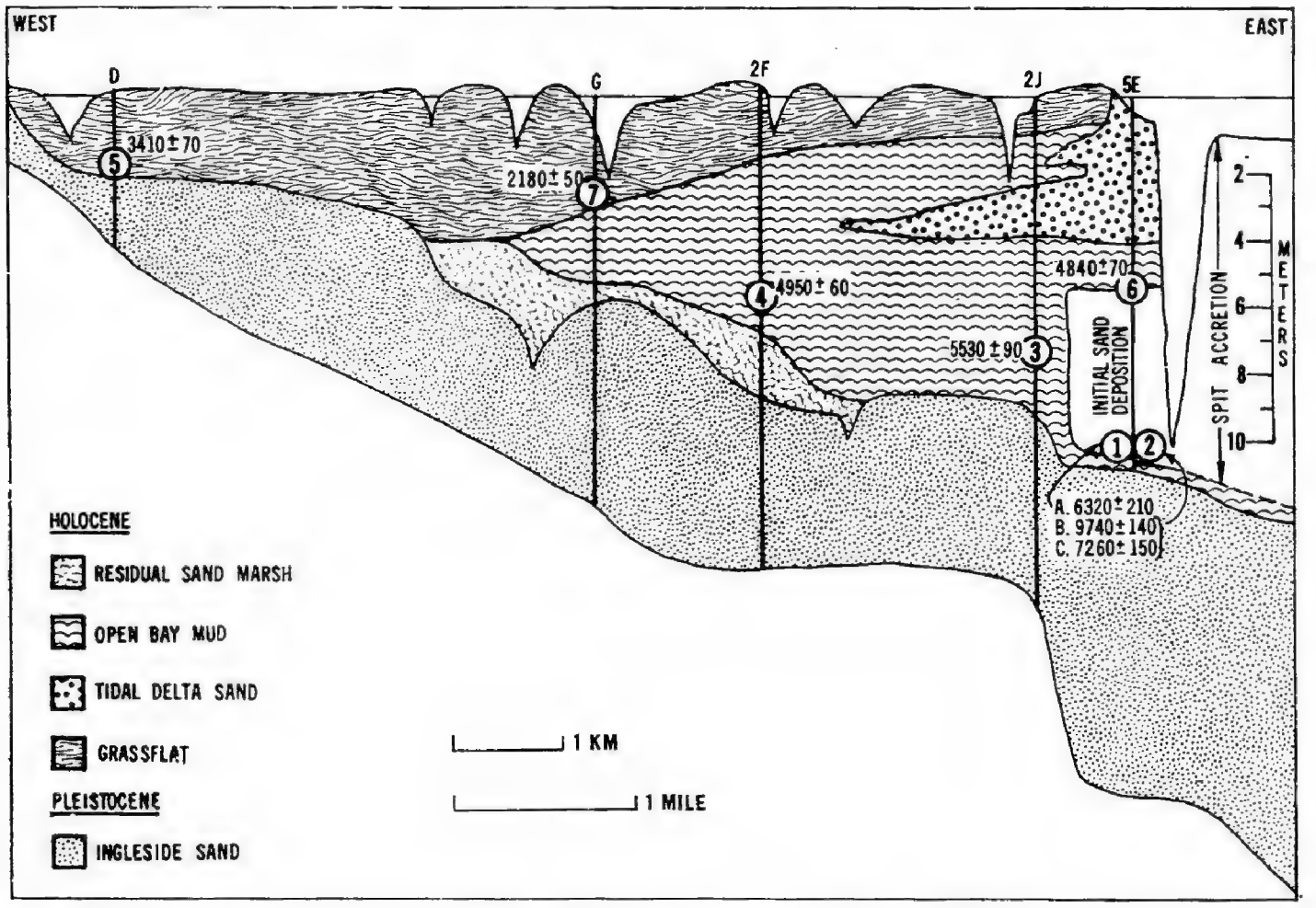

FIG. 3. Pleistocene-Holocene dip-section across central Harbor Island (slightly adapted from Munson 1975).

TABLE 1.

Data for sediment samples and depositional environment. Numbers in parentheses following sample numbers refer to Fig. 2 Harbor Island sample descriptions.

Sample Number	Depth below sea level (m)	^{14}C ·	δO^{18}	δC^{13}	Sample Material	Facies
Site 5E						
Tx-2310-A(1)	10.4	6320±210			clean, unaltered *Mulinia* shells	In basal barrier island sand, just above Holocene/ Pleistocene unconformity
Tx-2310-B	10.4	9740±140	-0.1	+0.1	blackened shell,[a] *Mulinia* and *Donax*	
Tx-2310-C(2)	10.4	7260±150	-0.3	+0.3	white echinoid (Mellita fragments, unweathered	
Site 2J						
Tx-2311 (3)	7.0	5530±90	-0.2	+0.9	mixed shell hash	In lower part of open-bay mud, 2.4-3.0 m above Holocene/Pleistocene unconformity
Site 5E						
Tx-2333 (6)	5.8	4840±70	-0.2	+0.7	*Mulinia* and *Donax*, black shell removed	Same site as Tx-2310; at top of barrier island sand unit
Site 2F						
Tx-2312 (4)	5.8	4950±60			mixed shell hash (black shell removed)	Near base of open-bay mud, about 1 meter above Holocene/ Pleistocene unconformity
Site D						
Tx-2313 (5)	2.1	3410±70	+0.1	+2.2	*Chione* and *Cerithidea*	Near base of grassflat, at Holocene/Pleistocene unconformity
Site G						
Tx-2334 (7)	2.7	2180±50[b]	0.0	+1.7	*Cerithidea*	Within grassflat facies

[a] weathered appearance - surface white and chalky where not blackened
[b] leak in system - only 75% recovery - may account for anomalous age

grassflat progradation from the west ultimately produced subaerial sections of Harbor Island. The average rate of sediment accumulation in the grassflat facies since 3400 years B.P. has been 0.06 meters per thousand years.

Sea Level

One of the aims of this study was to evaluate and augment the existing paleo-sea level data for the central Texas Gulf coast. Figure 2, which represents a compilation of most of the available data, indicates that the curve for the rise of sea level in this area from 10,000 years B.P. to the present should lie between those of Curray (1965) and Neuman (1971). They suggest that sea level rose continuously to its present position, at a rate that decreased sharply between 4500 and 3500 years ago, rather than in the step-like manner suggested by Frazier (1974) and Nelson and Bray (1970), and that sea level was still about one meter below present 2000 years ago on the Texas coast.

Stable Isotopes

Various authors have examined the effects of changing environmental conditions on the stable isotope composition of shell carbonate. Lloyd (1964) found that the gradient of $\delta^{18}O$ in Florida Bay mollusc shells, from +1‰ near the open Gulf to +3‰ at the northern end of the bay, was controlled by mixing with Gulf waters, evaporation of bay waters and influx of isotopically distinct fresh

water from the Everglades (notation indicates per mil deviation from the PDB standard). $\delta^{13}C$ varied according to the source of CO_2 for primary production (subsequently ingested and incorporated into shell carbonate). We measured these parameters in some of our samples in order to determine whether any similar environmental effects were apparent.

$\delta^{18}O$ in the open ocean is controlled by water temperature (higher temperature leads to lower $\delta^{18}O$ values). In restricted bodies of water, net evaporation can increase $\delta^{18}O$ (as it does in Florida Bay) while influx of isotopically "light" (low $\delta^{18}O$) river waters can decrease it. $\delta^{18}O$ variations in our samples were surprisingly low, ranging from -0.3 to $+0.1‰$ (Table 1). This low variability indicates either a constancy of water conditions over 6000 years (while the area changed from open Gulf to semi-restricted bay), which seems unlikely, or a balancing of the several factors which control $\delta^{18}O$ to produce little net change. Our $\delta^{18}O$ values yield paleo-temperatures of 20–22° C ($T = 16.5 - 4.3(\delta^{18}O_{shell} - \delta^{18}O_{water})$; Epstein and Mayeda 1953), assuming a Gulf of Mexico $\delta^{18}O$ value of $+1.0‰$ (Lloyd 1964; L. S. Land, personal communication). These temperatures are a little low, and may indicate the effect of local evaporation of the water, producing higher $\delta^{18}O$ values in the shells and thus lower calculated paleo-temperatures.

$\delta^{13}C$ values were more variable, though all fell within the range of normal marine shell carbonate (Keith Anderson and Eichler 1964). There is no evidence of "light" (low $\delta^{13}C$) carbon derived from the oxidation of terrestrial organic material, as Lloyd (1964) found.

SUMMARY

The history of growth of Harbor Island, a flood-tidal delta complex on the south-central Texas coast, has been documented using cuttings from jet-down borings and radiocarbon dating of stratigraphically important samples. Deposition of clean, well-sorted barrier island sand began at a depth of 10.4 meters below present sea level about 6300 years ago. Sand accretion continued, at a rate of 3.1 meters per thousand years, until about 4900 years B.P. By this time, the sand nucleus of the barrier island had expanded to partially restrict the bay behind it. An open bay mud facies accumulated beneath the present day Harbor Island for the next 1500 years, at the rate of 2.4 meters per thousand years. Further shoaling and restriction of the bay, combined with a decrease in the rate of sea level rise, led to the development of a submerged grassflat about 3400 years B.P., when sea level stood at 2.1 meters below present. Continued slow desposition of poorly-sorted muddy sand (0.06 meters per thousand years) led eventually to the emergence of parts of Harbor Island as wind-tidal flats, with the remainder of the island composed of intertidal grassflats.

The reliability of dated samples in this study and their probable location relative to sea level at the time of burial were carefully assessed for use in the construction of paleo-sea level curves. A compilation of published paleo-sea level data for the central Texas Gulf coast indicates that sea level rose continu-

ously to its present position, at a rate that decreased sharply between 4500 and 3500 years ago.

Stable carbon and oxygen isotope ratios from shell carbonates exhibit little influence of changing depositional environments over a period of about 6000 years.

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